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A model-based evaluation of flight crew performance of a new descent procedure

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A MODEL-BASED EVALUATION OF FLIGHT CREW PERFORMANCE OF A NEW DESCENT PROCEDURE

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ABSTRACT

A MODEL-BASED EVALUATION OF FLIGHT CREW PERFORMANCE OF A NEW DESCENT PROCEDURE

by Nancy M. Smith

This thesis presents model-based analyses of procedure tasks, requirements, and documents for a new airline flight crew procedure. The analyses identified problems with document descriptions of some procedure compliance requirements, and opportunities for document content to influence flight crew task selection and performance. Data collected during a simulator experiment comparing two sets of support documents showed between-group differences in task performance and procedure compliance that appeared related to document content. The model-based analyses provided insights into the relationship between observed performance and documentation, enhancing the information gained from procedure compliance measures and resulting in recommendations for specific changes to the procedure and its documents.

Acknowledgements

I have been extremely fortunate in the composition of my graduate committee: Dr. Todd Callantine, Dr. Kevin Corker, Dr. Louis Freund, Dr. Kevin Jordan, and Dr. Everett Palmer. The quality and variety of the assistance they provided has been critically important to me in developing and completing this thesis. I would particularly like to thank Dr. Everett Palmer for providing me the chance to learn about the practice of cognitive engineering in the aviation domain, and for his continual encouragement and intellectual support.

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Introduction

Activities performed by the human operators who work with complex dynamic systems are shaped by system technologies. Because these operators must perform a wide variety of functions, procedures are often used to structure and support their activity and to coordinate the distribution of activities, responsibilities, and information among them. As the capabilities of machines within these systems increases, new procedures will be needed to support changing demands on operator performance.

Developing procedures is a challenging task. Among the factors that complicate the design of procedures are uncertainties about what elements of human activity they should prescribe and about how they will be interpreted and performed by operators. Designers must also identify training methods for procedure introduction that are thorough enough to result in effective operator performance, yet inexpensive enough to keep the cost of system change affordable.

An iterative design process is currently the best way to deal with these uncertainties; however, iterative design can be time consuming and expensive. New methods to aid designers in developing, testing, and determining training requirements for procedures could expedite the process of adapting human activity to changes in complex dynamic systems, and help it keep pace with improvements in technology.

A MODEL-BASED METHOD FOR PROCEDURE EVALUATION

This thesis presents a task model-based approach to procedure evaluation, and describes its use to analyze data from a simulator experiment that compared two document-based methods for introducing a new airline flight crew procedure. Problems addressed during the development and evaluation of this procedure are representative of problems encountered in the development of procedures that support changes in complex dynamic systems. The analyses presented here show how a model-based approach can support development of this type of procedure.

This evaluation included five analyses that were based on a high-level model of the relationship between procedure-support documents and procedure compliance (Figure 1). As the diagram indicates, compliance results from operator performance of procedure-related tasks. Two knowledge requirements for successful task performance include: 1) understanding of the procedure's compliance requirements, so operators can formulate appropriate task goals; and 2) sufficient task knowledge for operators to choose appropriate methods to achieve those goals. Procedure-support documents can affect task performance (and thus, procedure compliance) by improving an operator's understanding and awareness of procedure requirements and methods available for meeting them.

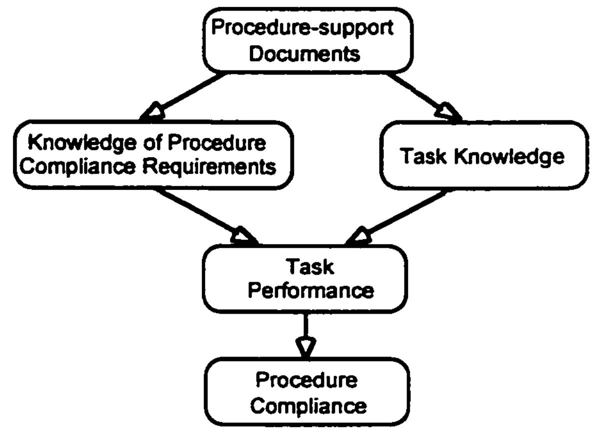


Figure 1. A dependency network illustrating the relationship between procedure support documents and procedure compliance.

Each of the analyses presented in this thesis focused on a particular element within this dependency structure. The "content analysis" of the procedure's documents decomposed the informational content of its support documentation. The "task analysis" developed a task model representing procedure-relevant task knowledge. The "overlay analysis" described the relationship between document content and procedure knowledge requirements. The "process analysis" of the experimental data identified the methods used and the timing of observed task performance. The "product analysis" obtained measures of procedure compliance.

Figure 2 shows relationships between inputs and outputs of the different analyses. Output from the product analysis provided a focus for the three model-based analyses of the procedure and its documents. These analyses, in turn, identified measures used in the process analysis of the experimental data to investigate the influence of document content on task performance.

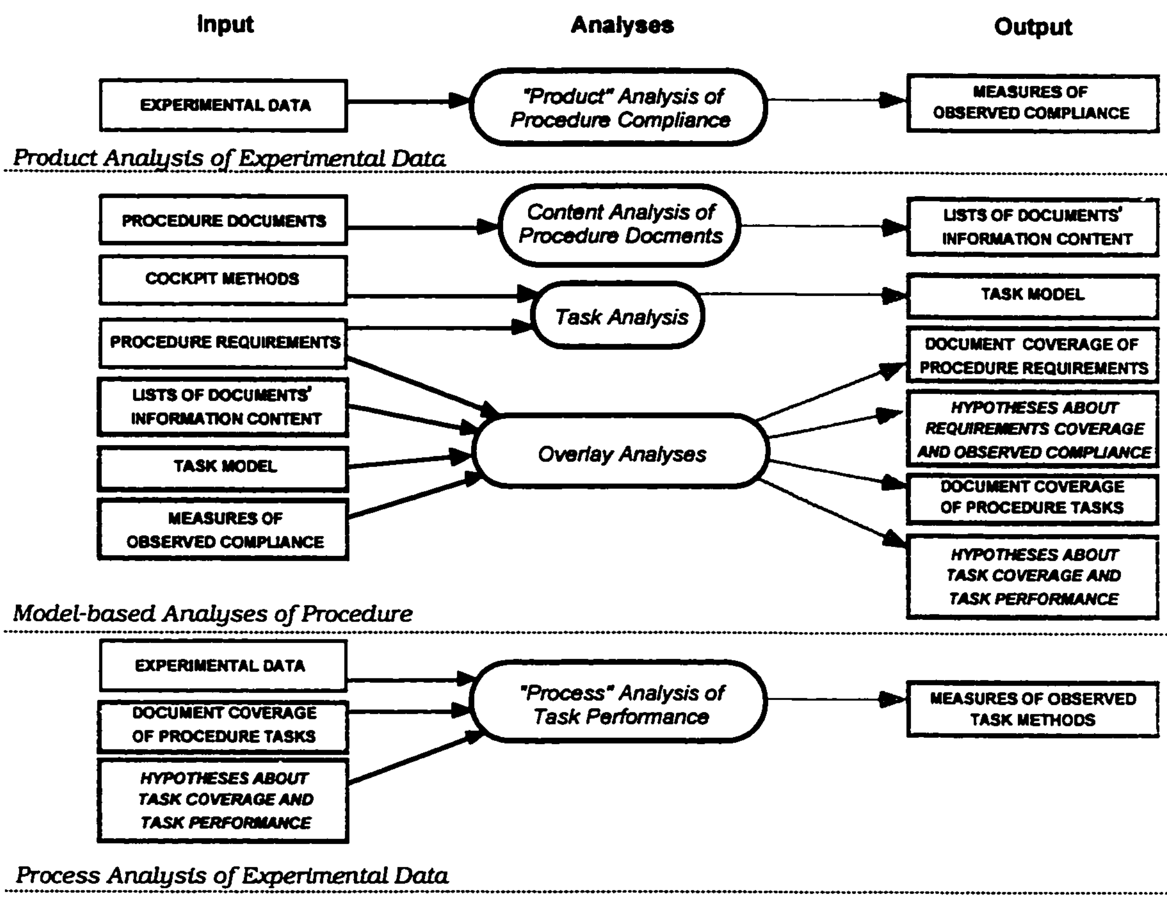


Figure 2. Input/output relationships among the five analyses. The input information required for each of the analyses is represented in the left-hand column; outputs from each analysis are shown in the gray boxes on the right. Gray boxes in the "Input" column represent output from a preceding analysis. The other four inputs are: "EXPERIMENTAL DATA," gathered during the simulator evaluation of the current procedure conducted in June, 1996; "PROCEDURE DOCUMENTS" and "PROCEDURE REQUIREMENTS," developed over the past several years, and "COCKPIT METHODS," the set of aircraft-specific methods available to flight crews for performing the procedure.

OVERVIEW OF THESIS CONTENT

The thesis is organized in five chapters. The first chapter describes operational procedures and the procedure development process. The second chapter describes the Precision Descent and the context for its development: the role of procedures in aviation, the computer-based air traffic control system that the procedure supports, prior evaluations of the system and the procedure, and the issues and constraints that influenced the procedure's current design. Chapter Three presents the Precision Descent training experiment: the two training conditions that were evaluated, the experiment's hypotheses and methods, and a discussion of some of the experiment's results. Chapter Four presents the model-based analyses of the Precision Descent and its documents. These include a task analysis of the procedure, content analysis of its documentation, an overlay analysis showing document coverage of task and procedure requirements, and a process analysis of the experimental data. Chapter Five summarizes the evaluation of between condition differences in flight crew performance of the Precision Descent, provides recommendations for changes in the procedure and its training, discusses the value of the analysis methods presented in this thesis, and describes possible future work in this area.

CHAPTER 1:

Operational Procedures

THE CONTENT AND PURPOSE OF OPERATIONAL PROCEDURES

Procedures furnish a specification for human activity, and serve a number of functions in operational settings. They insure correct performance of multi-step operations, guide execution of rarely performed tasks, reduce the operator's cognitive workload (providing memory aids and written 'recipes' to support performance), standardize task performance across operators, and provide expectations for what other agents will do (Callantine et al. 1997b; Degani & Weiner, 1994; Weiringa et al. 1993). Examples that illustrate these different operational uses include the troubleshooting procedures that help auto mechanics diagnose mechanical problems; resuscitation procedures for emergency medical personnel that allocate, order, and prioritize time-critical tasks; and standard operating procedures ("SOPs") used by airline flight crews to allocate tasks and responsibilities in the cockpit.

Procedures specify and structure operator activity by explicitly prescribing one or more attributes of an activity or task. The attributes specified and the level of detail in their specification vary depending on the procedure's purpose. These attributes include: who performs the activity, what the performer does, when or under what conditions the activity should be performed, what its immediate goals or target states are, and the proper sequence for performance of its component tasks. Callantine et al. (1997b) describe the varying levels of procedure specificity, stating that "a procedure is a way to 'chunk' useful operational information in an orderly fashion at salient levels of abstraction. For example, a procedure can specify how to perform a high-level function (e.g., write a report [select a topic, review the literature, draft an outline, etc.]), how to perform a task (e.g., save a document [access the File menu, select the Save option, enter filename, etc.]), or it can specify activity at multiple levels."

PROCEDURE DESIGN

The procedure designers' tasks include:

- defining procedure goals,
- composing an activity that achieves those goals,
- determining which aspects of that activity must be explicitly prescribed,
- determining the appropriate level of abstraction for task specification,
- identifying means to communicate procedure requirements,
- developing training requirements and methods for procedure introduction,
- determining what kind of operational support is needed for procedure execution,
- creating artifacts to provide that support.

Results from these different activities can interact in ways that force revision of earlier design decisions; for example, determining that a procedure is difficult or costly to train might require changes to the procedure's specifications.

Though guidelines exist for procedure design, the process still relies on the designers' skill, imagination, and operational experience. Because of this, it is important that the design team represent all operator groups who will be affected by a procedure's use (Degani & Weiner, 1994). ATC procedures, used to coordinate aircraft flight trajectories between controllers and pilots, illustrate the need for design teams to include different user populations.

Because even qualified domain experts (controllers, fleet captains, line-check pilots, and flight instructors in the above case of ATC procedures) can find it difficult to anticipate how a procedure will be interpreted and performed, Degani and Weiner advise simulator testing with a sample from the target population of users (1994). In practice, an iterative cycle of design, test, evaluate, then modify design, retest, etc., is usually needed before satisfactory performance is achieved. This iterative cycle may include redefinition of procedure requirements, revision of training materials, or changes in task structure. This can be a slow and expensive process, and methods that would support designers in defining a procedure, determining its training requirements, and conducting simulator evaluations are badly needed.

The present study represents the latest evaluation phase in an iterative design-test-revise process of procedure development that has continued for the past several years. A series of evaluations involving practicing line pilots have preceeded this latest simulator study. These included part-task and full-mission simulations conducted at NASA Ames Research Center and at two airline training centers, and two extensive field evaluations at Denver's Stapleton and International Airports. Domain experts (training and line pilots, controllers, and system designers) have been participants in this project from its beginning. Nevertheless, each evaluation revealed problems with the procedure or its documents: in terms of pilot or controller workload and responsibilities, the clarity and completeness of presentation of procedure requirements, and the consequence of operational variations to the procedure or its clearances. An approach to design that would permit developers to systematically analyze aspects of the procedure in advance of periodic evaluations might enable more effective use of the information the evaluations provide, and could accelerate and reduce costs associated with development. The current project, with its constraints on time, resources, and performance requirements is a good opportunity to determine whether task modeling can provide an analytical framework that facilitates development.

New Procedure Introduction

Procedure designers must also determine how best to introduce a procedure into operational practice. The amount of training needed for procedure introduction is determined, in part, by the criticality of correct performance, the procedure's 'novelty', and the effectiveness of operational performance support that can be provided. One method of supporting procedure execution is with paper documents: examples of procedure-support documents used in aviation include ATC charts, checklists, flight manual bulletins, and procedure manuals. If a procedure's requirements can be clearly presented to operators using these materials, and appropriate methods for its performance are apparent to them, this support may be sufficient for its introduction and no added training may be needed. If method selection, timing, or procedural task dependencies are important, a document that prescribes an explicit sequence of steps can be used to insure correct performance. If new methods are needed for the procedure, some form of classroom or simulator training may be needed.

Identifying an effective means for introducing a procedure can be critical to the success of the system it was intended to support; inadequate training could result in mediocre or even dangerous system performance. However, the cost of training may prohibit the widespread adoption of a procedure (or system) whose benefits don't outweigh that cost. This tradeoff creates a strong incentive to identify the minimum training required for introduction of any new operational procedure.

Factors Affecting Procedure Design

A variety of factors complicate procedure design and training. These include:

- The operator's prior experience: understanding (and acceptance) of a procedure is supported and complicated by knowledge of goals and methods for similar procedures (Degani & Weiner, 1994; Weiringa et al. 1995).
- The physical task environment: the media for communicating and representing task information, the system interface, and the design of automated control systems can structure, support, and constrain task activity (Hutchins, 1995; Palmer et al. 1994). Effective use of these system elements requires a thorough understanding of its structure, interface, and displays.
- The task context: other activities, time pressures, SOP task distribution, and the consequences of incorrect performance affect the manner in which tasks are performed (Palmer, 1995).

MODEL-BASED PROCEDURE DEVELOPMENT

Degani and Weiner (1994), Mitchell (1997), and Callantine et al. (1997b) recommend use of a hierarchical task model to clarify procedure requirements and support the design process. A hierarchical organization can represent a procedure's high-level goals and the activities needed to accomplish those goals, along with their component tasks, subtasks and actions (Callantine et al. 1997a; Mitchell, 1997). These models can also represent attributes of a procedure's tasks and its operational environment; including information requirements, who performs specific activities, the system displays and interface used to perform actions and access information, or any constraints imposed by a specific task context (Callantine et al. 1997b; Hutchins, 1995; Palmer et al. 1993).

Task models can provide a structured description of the factors that influence operator learning and task performance, and model-based representations of procedure activities and context have a number of potential uses for designers. These representations can provide a framework for analysis of a procedure's operator workload demands, critical task dependencies, information dependencies, and potential conflicts with its operational environment (Callantine et a[1] 1997b; Mitchell, 1997; Palmer et al. 1993; Riesbeck & Hutchins, 1982). Task models can also help designers identify needed training and/or operational support, the system knowledge needed to perform the procedure correctly, and opportunities for misunderstandings and performance errors (Kieras, 1988, 1990; Kitajima & Polson, 1992; Means, 1993). Finally, task models can provide a standard for performance analysis (Callantine et al. 1997ab; Lesgold et al. 1990).

This thesis explores some of these uses for task modeling in procedure design. It develops a task model representing the activities involved in procedure compliance and the information requirements and system characteristics that constrain performance of those activities. This model is then used as a framework for evaluating the procedure and the adequacy of information provided in its training material, and for analyzing observed crew performance.

CHAPTER 2:

Aviation Procedures and the Precision Descent

BACKGROUND

Recent applications of computer technology in aviation have profoundly altered the air traffic management system. The past several years have seen the introduction of increasingly sophisticated cockpit automation systems, computer-based tools for air traffic control, communication technologies that allow exchange of information between aircraft and ground-based computers, satellite-based systems for accurate position determination, and on-board collision avoidance systems. These new tools change the information available to flight crews, controllers, and airline dispatch personnel about individual aircraft, weather, and air traffic patterns. Effective use of this technology will require widespread changes in the distribution of tasks and responsibilities among these agents, redefining the roles of air traffic control, the airlines, and individual flight crews. New protocols for air-ground coordination of flight path will be needed, along with new procedures to support human performance within this altered system.

AVIATION PROCEDURES

Commercial aviation already depends on the use of procedures to conduct its operations. ATC procedures, maintenance procedures, standard operating procedures (SOPs), flight manual procedures and checklist procedures represent just a few examples of procedures that support operator activities in this system. Two types of aviation procedures concern us in the present study: cockpit procedures and ATC procedures.

Cockpit Procedures for Task Specification

Cockpit procedures specify aspects of the "process" of task performance, providing "how-to-do-it" constraints that standardize the performance of unfamiliar, complex, or error-prone tasks. Cockpit procedures may be supported by a written checklist or a flight manual page that describes a method or sequence of steps for task execution.

Not all cockpit activity is "proceduralized" and not all cockpit procedures are highly specified, nor should they be. Degani and Weiner (1994) describe the relationship between "techniques" -- the methods an individual pilot chooses to perform an activity -- and "procedures," which standardize performance between pilots. Techniques offer a skilled pilot the chance to elaborate and improve upon an activity that has not been fully specified. Degani and Weiner warn that "over-procedurizing" the cockpit -- over-specifiying cockpit activity -- not only denies pilots the opportunity to exercise appropriate judgement and skill in task performance, but can result in an inflexible operational environment that may adapt poorly to varying conditions. An excessively constrained environment can also lead to chronic violation of procedures that pilots find arbitrary and restrictive. These procedure violations may represent serious safety hazards. According to a recent study conducted by the National Transportation Safety Board, procedure non-compliance was identified as a major contributing factor in airline accidents (National Transportation Safety Board, 1994).

ATC Procedures for Flight Path Assignment

Air traffic controllers and pilots need to have accurate, shared knowledge of the location and intended flight path of individual aircraft. Established protocols exist for communicating this information between air and ground; these protocols rely primarily on a standardized language for radio voice communication that can be supplemented by published, route-specific procedures. ATC procedures provide an efficient mechanism for a controller to communicate a standard sequence of flight path constraints to a flight crew, and are frequently used to organize air traffic departure and arrival patterns around an airport. A special clearance assigns the ATC procedure by name, and directs the flight crew to a published chart which presents an explicit series of flight path constraints that the aircraft must follow. These constraints define a portion of the aircraft's route, and may include a sequence of waypoints with a corresponding set of altitude and/or speed constraints. The purpose of these procedures is to reduce the radio communication needed to coordinate a standardized flight path between air and ground by providing a mechanism for assigning a complex trajectory to an aircraft.

ATC procedures describe, in Degani and Weiner's terms, "what the task is" (1993). They specify the target flight path -- the desired "product" of flight crew activity -- but, with very few exceptions, they do not specify the methods the flight crew must use to achieve this assigned path. If successful compliance with this target flight path is method dependent, a cockpit procedure may be used to constrain method selection. If compliance is not method dependent, however, reliance on flight crew techniques for ATC procedure execution is probably preferred: pilot technique can be more adaptive to varying conditions and it requires less training and operational support.

THE CENTER-TRACON AUTOMATION SYSTEM (CTAS) AND THE DESCENT ADVISOR

NASA has developed a set of new computer-based air traffic control tools called the "Center-TRACON Automation System," or CTAS. CTAS uses predicted flight trajectories for individual aircraft to generate advisories that assist controllers in the management of aircraft arriving at an airport. These trajectory predictions are based on aircraft type-specific performance models, and use current wind measurements along with the aircraft's current airspeed, altitude, heading, and flight plan (Erzberger, 1994). One part of CTAS, the Descent Advisor (DA), is designed to predict an aircraft's position along a known descent trajectory. The DA uses this predicted descent trajectory to identify potential conflicts between aircraft and to estimate when each aircraft will arrive at a "metering waypoint" on the descent path. The DA then presents controllers with a top of descent point and cruise and descent airspeed advisories designed to improve the sequencing and spacing of these aircraft at the metering waypoint in preparation for landing (Williams & Green, 1991).

CTAS/DA Descent Procedures

The CTAS descent procedure consists of a set of vertical flight path constraints that are intended to match an aircraft's descent path to the path generated by the Descent Advisor. Air traffic controllers communicate these constraints to flight crews using special ATC clearances. These CTAS descent clearances provide an assigned descent airspeed, an assigned descent point, and speed and altitude restrictions at the metering waypoint.

Flight Crew Methods for Procedure Compliance

This CTAS Descent Procedure may currently be used for aircraft that fall into three different categories: turboprop commuter aircraft, commercial jets equipped with Flight Management Systems (FMS), and non-FMS-equipped commercial jets. The trajectory expectations and corresponding procedure requirements differ for each of these aircraft types because of the different methods available to crews to conform to an assigned descent profile. Some of the issues related to performance of the CTAS Descent for all three classes of aircraft are described elsewhere (Cashion et al. 1995; Palmer et al. 1997; Green & Vivona, 1996). The present discussion will describe methods for flying a CTAS descent in the Boeing 747-400, a representative example of an FMS-equipped aircraft.

Modes, Methods and Issues for FMS-equipped Aircraft

One of the main issues for the 747-400 is related to the level of automation (or autoflight "mode") that the flight crew selects to initiate descent and to manage the vertical profile during descent. The crew has a number of different options; two commonly used descent modes that are well suited to fly CTAS Descent profiles are "Vertical Navigation" (VNAV) mode, and "Flight Level Change" (FLCH) mode. Both are compatible with CTAS descents but each has some specific advantages and limitations.

CTAS descents in "VNAV" mode. When provided with a downpath crossing restriction (a lower altitude and a speed constraint associated with a waypoint), the FMS calculates a top-of-descent location (T/D) that defines an idle-power descent profile extending from cruise altitude to that downpath constraint. Engaging VNAV mode after this descent profile has been determined results in the FMS automation controlling the aircraft to fly that vertical profile, with little or no pilot action needed. Upon reaching the VNAV calculated T/D, the autothrottle system retracts the throttles to idle and the autopilot system adjusts the pitch to follow the computed vertical path.

The computed descent path includes a deceleration and level-off segment at the bottom of descent that enables the aircraft to meet the specified waypoint crossing restriction. During descent, the pilot's Navigation Display shows a representation of the aircraft's vertical deviation from the FMS-computed descent profile. This display is available even when VNAV is not engaged, and can be used to assess the aircraft's ability to acquire the downpath crossing restriction.

The trajectory calculation performed by the FMS is essentially equivalent to the calculation performed by CTAS; in fact, CTAS is often described as a "ground-based FMS" (Palmer et al. 1997). However, each system performs its trajectory calculation independently, based on its own representation of current flight conditions and targets. Unless the two systems are provided the same input information, there is the real possibility that their resulting flight trajectories will fail to match. Thus, before using VNAV to manage the Precision Descent, the pilot must 1) program the FMS with the information needed for correct path calculation (descent forecast winds, assigned descent speed, and metering waypoint crossing restriction), and 2) verify that the resulting descent trajectory matches the assigned trajectory.

CTAS descents in "FLCH" mode. Flight Level Change (or "FLCH") is a lower-level automation mode that can also be used to fly CTAS descents. When the FLCH mode is engaged, the throttles are automatically retracted to the idle position, and pitch is adjusted to maintain a pilot-specified airspeed or mach target. FLCH mode will not automatically capture a programmed, waypoint-associated speed or altitude restriction, nor can it be used to automatically initiate descent at a future location. However, FLCH can result in less deviation from the assigned descent speed because it actively adjusts pitch to maintain the target speed; VNAV's speed tolerance is less precise because it relies on the descent path calculation to produce a trajectory that will result in the desired speed during idle descent.

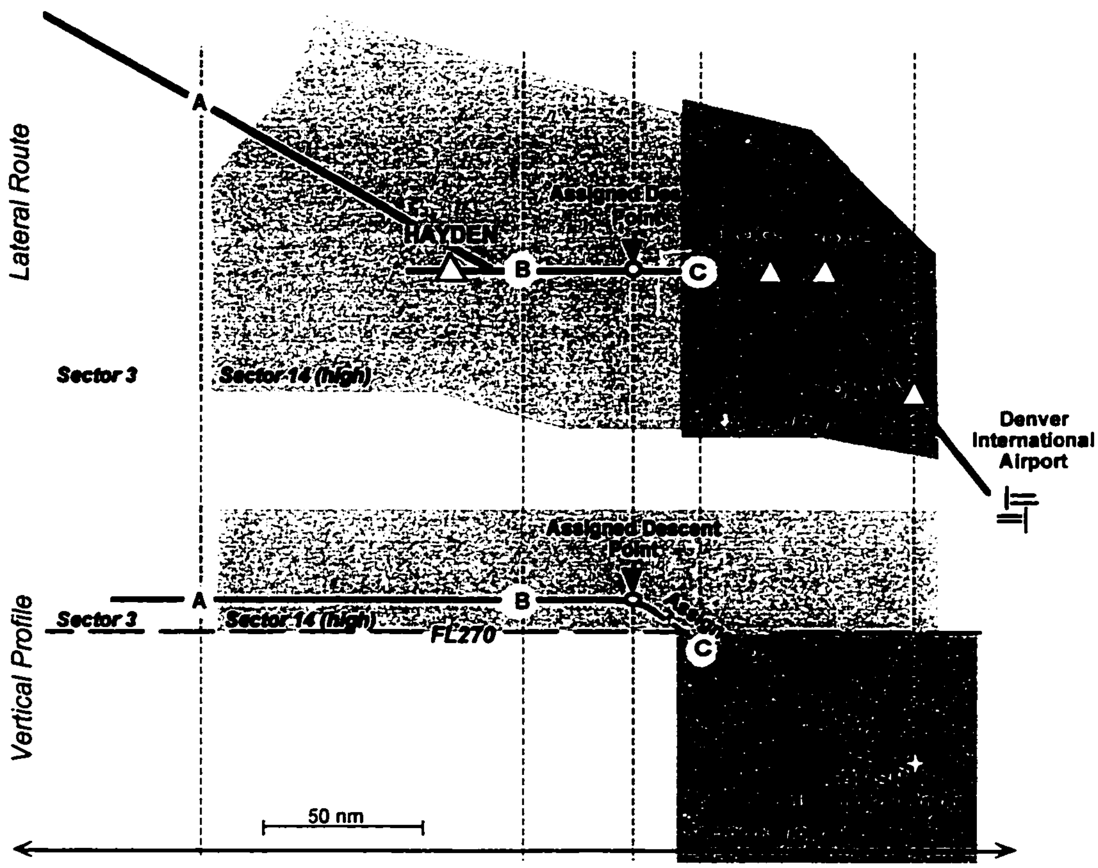
Thus, flight crew tasks during a CTAS descent differ depending on which autoflight mode is selected. While VNAV provides a fully-automated mode for flying the Precision

Descent from start to finish, it must be properly configured, its path calculation checked against the assigned descent path, and airspeed monitored in descent for deviations that may need thrust or drag adjustments. FLCH is simpler to set up and provides closer maintenance of the assigned descent speed, but leaves the pilot the responsibility of beginning the descent at the right location and determining where and when to decelerate and level-off in order to meet the assigned crossing restriction. Since neither autoflight mode is clearly superior for all descent contexts, it is probably appropriate to leave selection of the CTAS descent mode to the flight crew.

Descent Advisor Field Evaluations

NASA researchers, working with the Federal Aviation Administration (FAA), United Airlines, Mark Air, and Mesa Airlines, conducted a field evaluation of the CTAS/DA in the Denver area in 1995 (Green & Vivona, 1996; Palmer et al. 1997). This evaluation tested the accuracy of the DA's arrival time predictions for commercial flights arriving at Denver International Airport. 185 aircraft participated in this evaluation, including nine different aircraft types. Flight crews who participated in the field evaluation received a standard Jeppesen chart describing the CTAS/DA clearances as part of a "CTAS Descent Procedure" to be flown during the evaluation. Aircraft-specific flight manual bulletins that described how to comply with the procedure were distributed by the airlines to pilots in each participating fleet. NASA researchers developed these procedures and documents with design assistance from airline pilots, airline training staff, and air traffic controllers. Qualified line pilots participated in simulator testing of the procedure, clearances, and briefing documents as they were developed.

Despite the care taken during procedure design, problems were observed during the Field Evaluation that indicated that the clearances were too long and contained too much information (Palmer et al. 1997). Pilots often needed to have clearances repeated or clarified, and frequent readback errors occurred. Controllers were concerned about the length and number of communications needed for each aircraft. Because of an altitude sector boundary at 27,000 feet (flight level 270, or FL270), two descent clearances had to be issued: the first cleared the aircraft from cruise altitude to FL270, and the second, following the handoff to the low altitude controller, from FL270 to the metering fix (Figure 3). The need for two descent clearances was explained in the procedure documents, but still resulted in crew misunderstandings about the procedure's intent and compliance requirements.



A Initial CTAS Notification (Sector 3):
"Company 123, expect CTAS descent, expect to cross TOMSN at FL190 and 250 knots, maintain FL___."

B Descent Clearance (Sector 14):
"Company 123, maintain FL___ until __miles E/W of __, descend and maintain FL270, maintain __Mach/ __knots in the descent."

C Further Descent Clearance (Sector 13):
"Company 123, continue descent at __knots, cross TOMSN at and maintain FL190 and 250 knots."

Figure 3. CTAS Descent Procedure and clearances used in 1995 Field Evaluation. The upper half of the figure represents the lateral route flown by participating aircraft; the lower portion shows the CTAS vertical profile.

THE PRECISION DESCENT: A NEW CTAS DESCENT PROCEDURE

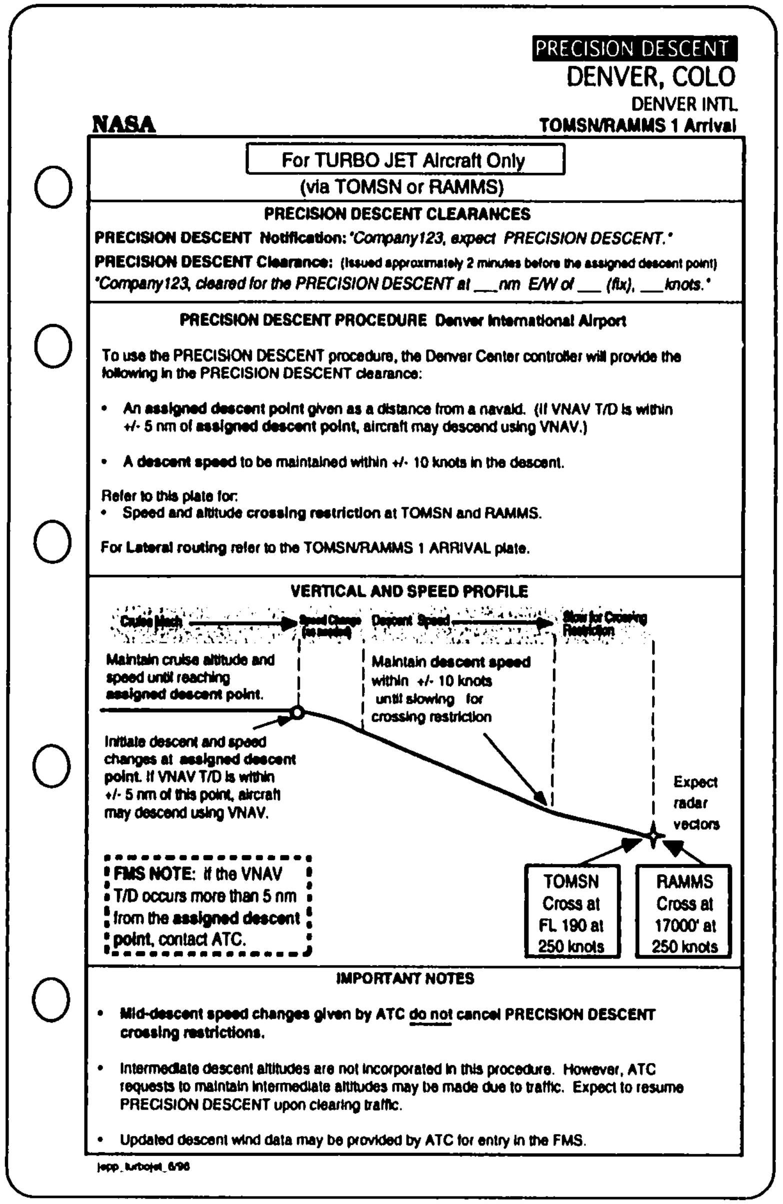
Pilot and controller participants from the 1995 Field Evaluation met with NASA researchers in February 1996 to review results from the evaluation and to discuss possible improvements to the procedure. Their suggestions included 1) reducing clearance length by transferring some of the needed procedure information to a published chart, 2) simplifying clearance handling at the altitude sector boundary in the descent path, and 3) changing the procedure's name. These suggestions resulted in the "Precision Descent" procedure flown by pilots in the present simulator study. Unlike the CTAS Descent Procedure, the Precision Descent uses terse, non-standard clearances that rely on a procedure chart for their correct interpretation.

A Charted Procedure

Clearance phraseology used in the 1995 Field Evaluation was designed to be as standard as possible, and to stand alone. The use of a published, charted procedure to communicate compliance requirements for the Precision Descent reduces the amount of information that needs to be provided to flight crews by air traffic controllers and allows the use of shorter, non-standard clearance phraseology. Non-varying compliance requirements (the bottom-of-descent crossing restrictions) are stated in the Chart itself, leaving only the descent information that varies with each flight (descent airspeed and Assigned Descent Point) to be communicated in special clearances. The Chart (Figure 4) also explains the non-standard, abbreviated terminology used in these two clearances.

"Precision Descent" Name

The CTAS Descent Procedure was renamed the Precision Descent to avoid confusion of "C-TAS" with "T-CAS" (an acronym for Traffic Collision Avoidance System). It was also intended to remind pilots of the "Profile Descent," an established descent procedure that also includes a sequence of altitude and speed restrictions.



PRECISION DESCENT

DENVER, COLO

DENVER INTL

NASA — TOMSN/RAMMS 1 Arrival

For TURBO JET Aircraft Only

(via TOMSN or RAMMS)

PRECISION DESCENT CLEARANCES

PRECISION DESCENT Notification: *'Company123, expect PRECISION DESCENT.'*

PRECISION DESCENT Clearance: (Issued approximately 2 minutes before the assigned descent point)
'Company123, cleared for the PRECISION DESCENT at ___nm E/W of ___ (fix), ___knots.'

PRECISION DESCENT PROCEDURE Denver International Airport

To use the PRECISION DESCENT procedure, the Denver Center controller will provide the following in the PRECISION DESCENT clearance:

- An **assigned descent point** given as a distance from a navaid. (If VNAV T/D is within +/- 5 nm of **assigned descent point**, aircraft may descend using VNAV.)
- A **descent speed** to be maintained within +/- 10 knots in the descent.

Refer to this plate for:
- **Speed and altitude crossing restriction** at TOMSN and RAMMS.

For **Lateral** routing refer to the TOMSN/RAMMS 1 ARRIVAL plate.

VERTICAL AND SPEED PROFILE

IMPORTANT NOTES

- **Mid-descent speed changes given by ATC do not cancel PRECISION DESCENT crossing restrictions.**
- Intermediate descent altitudes are not incorporated in this procedure. However, ATC requests to maintain intermediate altitudes may be made due to traffic. Expect to resume PRECISION DESCENT upon clearing traffic.
- Updated descent wind data may be provided by ATC for entry in the FMS.

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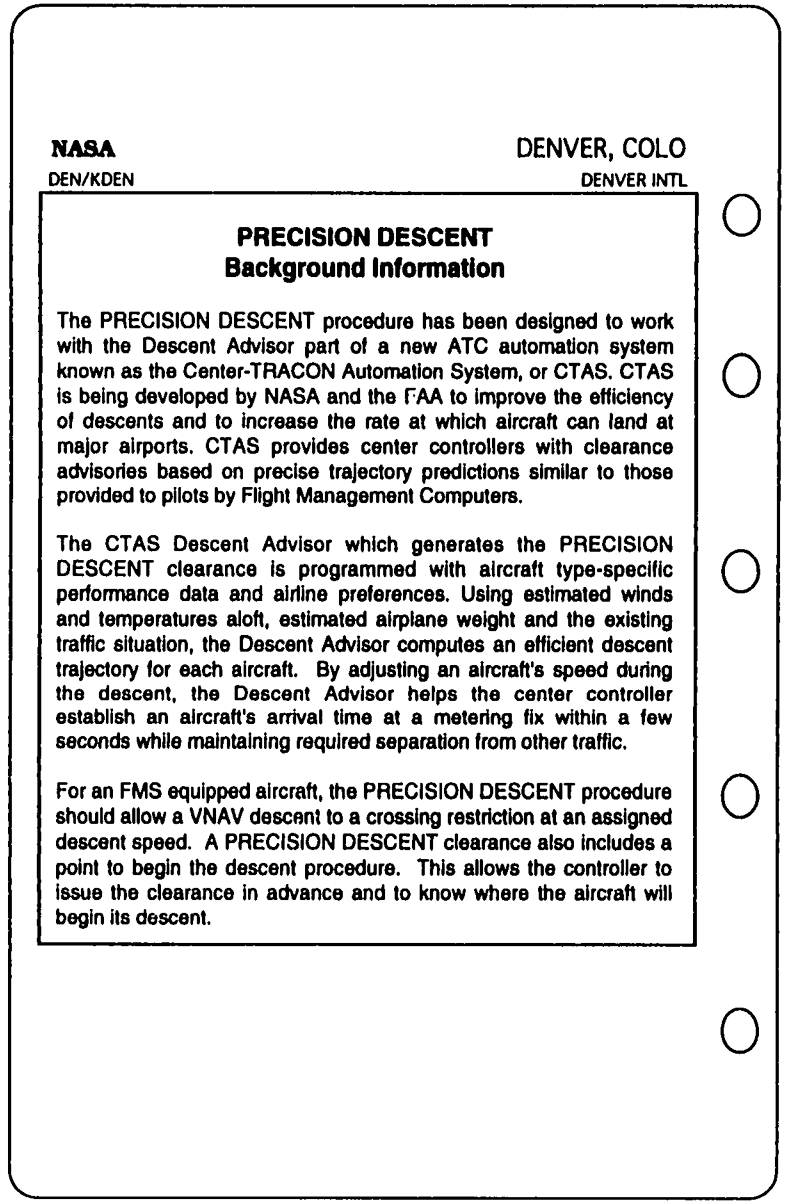
Front side.



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PRECISION DESCENT
Background Information

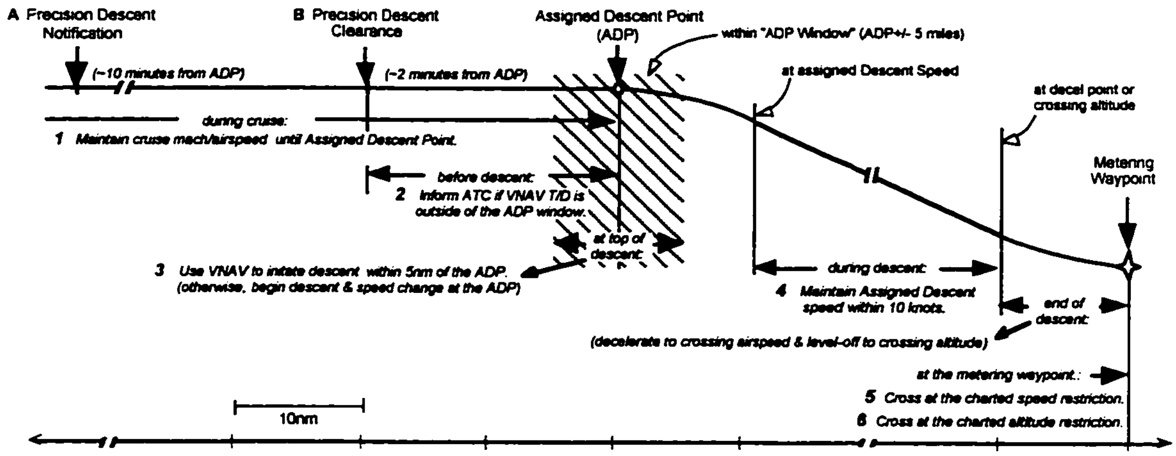
The PRECISION DESCENT procedure has been designed to work with the Descent Advisor part of a new ATC automation system known as the Center-TRACON Automation System, or CTAS. CTAS is being developed by NASA and the FAA to improve the efficiency of descents and to increase the rate at which aircraft can land at major airports. CTAS provides center controllers with clearance advisories based on precise trajectory predictions similar to those provided to pilots by Flight Management Computers.

The CTAS Descent Advisor which generates the PRECISION DESCENT clearance is programmed with aircraft type-specific performance data and airline preferences. Using estimated winds and temperatures aloft, estimated airplane weight and the existing traffic situation, the Descent Advisor computes an efficient descent trajectory for each aircraft. By adjusting an aircraft's speed during the descent, the Descent Advisor helps the center controller establish an aircraft's arrival time at a metering fix within a few seconds while maintaining required separation from other traffic.

For an FMS equipped aircraft, the PRECISION DESCENT procedure should allow a VNAV descent to a crossing restriction at an assigned descent speed. A PRECISION DESCENT clearance also includes a point to begin the descent procedure. This allows the controller to issue the clearance in advance and to know where the aircraft will begin its descent.

Back side.

Figure 4. Precision Descent Procedure Chart



A Precision Descent Notification (Sector 3):
"Company 123, expect Precision Descent."

B Precision Descent Clearance (Sector 14):
"Company 123, cleared for Precision Descent, __miles E/W of __, __Mach/__ knots."

Figure 5. The Precision Descent: clearances and compliance requirements.

Eliminate Sector Boundary Clearance

The Precision Descent eliminates the need for a second descent clearance before crossing the high/low altitude sector boundary by having the high altitude controller clear the aircraft from cruise altitude to the metering waypoint in the low altitude sector. Standard clearances can be used when needed to stop the aircraft at the sector boundary (or any other mid-descent altitude).

PRECISION DESCENT COMPLIANCE REQUIREMENTS

Figure 5 illustrates the procedure's compliance requirements and the timing of its clearances. After an initial "Notification" from the controller to expect clearance for the Precision Descent, crews are issued a "Precision Descent Clearance" roughly two minutes before descent is to begin. This clearance includes an Assigned Descent Point (ADP) and an Assigned Descent Speed (ADS). Descent and speed changes must begin within 5 nautical miles of the ADP, and cruise altitude and airspeed maintained until the aircraft reaches this 10 nautical mile "ADP Window." Once acquired, the ADS must be maintained within 10 knots. The Precision Descent also includes a charted crossing restriction at the metering waypoint, which ends the procedure.

CHAPTER 3:

Experiment

FLIGHT CREW TRAINING FOR THE PRECISION DESCENT

The Precision Descent clearances provide a mechanism for an air traffic controller to communicate a DA-specified descent profile to an airline flight crew. An effective method for training this ATC procedure is needed for the capabilities of the DA to be fully utilized. If training is inadequate, compliance with the assigned descent trajectory will be poor, and the performance of the system will be compromised. On the other hand, the cost to airlines of one or two hours of high-fidelity simulator training may be prohibitive, and limit the operational use of the procedure.

Purpose of Experiment

A simulator evaluation of the Precision Descent was conducted in June, 1996. Eight flight crews flew eight Precision Descents in a high fidelity Boeing 747-400 simulator. The evaluation included a between-group comparison of two document-based methods for procedure introduction. This comparison was intended to establish whether either condition resulted in adequate crew performance of the procedure. If neither condition proved sufficient, classroom or simulator training might be needed.

Related to the question of the need for formal training is the issue of whether pilot technique (even when supported by a bulletin's recommendations) can be relied on for correct task interpretation and performance. If task performance is inadequate in both conditions, a method-specific cockpit procedure may be required.

Procedure training vs. procedure support. In addition to the cost of formal training, there is an added reason for preferring to rely on document-based training: these documents will be available to support operational task performance whenever the procedure is used. Because the DA's introduction into operational use will be gradual (initially limited use at a limited number of air traffic control centers), a pilot's first operational encounters with the Precision Descent procedure will probably be infrequent. If there is a long interval between procedure training and procedure performance in the field, or even between repeated operational encounters with the procedure, the effectiveness of training or prior experience will be reduced. If a method is used for procedure introduction that relies on operational support and not on formal training, that support can be available whenever it is needed (presuming, of course, that the flight crew remembers that the material is available and chooses to use it).

TWO TRAINING CONDITIONS

Two different training conditions were tested to determine whether either provided flight crews with enough information for satisfactory performance of the Precision Descent. One experimental condition tested the adequacy of a "Precision Descent Chart" alone for procedure introduction (Figure 4). This Chart explained the new ATC procedure's clearances and compliance requirements, and was comparable to a procedure chart from the airline pilot's Jeppesen manual. Because the Precision Descent does not introduce any new tasks for experienced flight crews, the statement of ATC compliance requirements and explanation of clearance content contained in a procedure Chart might be sufficient for correct performance.

The second condition used a more conservative approach to procedure introduction, supplementing the Chart with a document that recommended specific methods for complying with the descent procedure (Figure 6). Half of the crews received a Precision Descent "Flight Manual Bulletin" patterned after documents used by airlines to provide method recommendations for specific flight activities. This Bulletin described methods that could be used to comply with some of the procedure's tasks. All of these suggestions should have been familiar to experienced pilots, and the Bulletin added no new information about Precision Descent compliance requirements. Both procedure charts and method-description bulletins are familiar documents to commercial airline pilots, and are used regularly to support in-flight task performance.

FLIGHT MANUAL BULLETIN

Insert 747-400-96-06

Remove N/A

JUNE 1/96

PRECISION DESCENT CLEARANCE AND TECHNIQUE

The PRECISION DESCENT Clearance is currently being evaluated at Denver ARTCC. Descent clearance information used in this procedure is generated by a new air traffic control computer system, and is intended to be compatible with VNAV. The suggested technique below demonstrates how VNAV may be used to comply with the PRECISION DESCENT.

Notification:

"United 123, expect PRECISION DESCENT."

NOTIFICATION

Notification to expect the PRECISION DESCENT clearance will be received approximately 10 minutes before descent.

- Prepare to comply by entering the crossing restriction from the PRECISION DESCENT PLATE in the CDU LEGS page.

FORECAST WINDS

Descent Forecast Winds may be provided to the aircraft by ATC. If forecast winds are provided:

- Enter in the DES FORECAST page.

PRECISION DESCENT Clearance:

"United 123, cleared for PRECISION DESCENT, 20 nm West of FROGS, 300 kts**."*

** **assigned descent point:** actual values will vary*

*** **assigned descent speed:** actual values will vary*

DESCENT POINT

The aircraft may descend using VNAV if the VNAV T/D is within 5 nm of the assigned descent point.

To compare the VNAV T/D to the assigned descent point:

- Enter the assigned descent speed in the DES page, then recompute the VNAV T/D.
- Refer to the PROG page to determine the distance between the new VNAV T/D and the assigned descent point. (see ***EXAMPLE***).

If the VNAV T/D is within 5 nm of the assigned descent point:

- Plan to use VNAV to initiate and fly the descent.

If the VNAV T/D is *not* within 5 nm of the assigned descent point:

- Inform ATC.
- Plan to recapture the VNAV path after descent has been initiated.
- Consider using ALT HOLD to prevent early descent while waiting for descent clearance.

CRUISE-TO-DESCENT SPEED TRANSITION

Note that VNAV's descent initiation method is compatible with the recommendations below.

If assigned descent speed is slower than cruise airspeed:

- Begin deceleration ***after*** reaching the assigned descent point.

If assigned descent speed is faster than cruise airspeed:

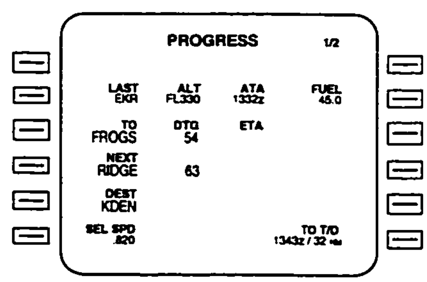
- Maintain cruise or assigned mach until assigned airspeed is reached.

SPEED IN DESCENT

- Use thrust or drag as needed to maintain assigned descent speed within 10 kts.

EXAMPLE

"...20 nm West of FROGS, 300 kts."



In this example, the aircraft is 54 miles west of FROGS and 32 miles west of the VNAV T/D. Therefore the T/D is 22 miles west of FROGS, or 2 miles from the assigned descent point.

NASA FLIGHT MANUAL BULLETIN

PAGE 1 OF 1

Figure 6. Flight Manual Bulletin for Precision Descent

A Comparison of Methods: Initial Hypotheses

The two training conditions in this experiment compare a statement of procedure compliance requirements with a second condition that adds a procedure "recipe." The cost and effort associated with the second condition is higher, requiring development and distribution of airline and aircraft specific bulletins. It may also prove that for experienced flight crews, added instruction on familiar tasks is unneeded and possibly even detrimental to performance. Our expectation before conducting this simulator study was that the Bulletin would influence (and possibly improve) the efficiency of the methods pilots used to fly the Precision Descent, but not affect their compliance with the procedure's trajectory requirements. This distinction between "product" and "process" outcomes, and arguments favoring either the "Chart Only" or the "Chart with Bulletin" method are summarized by the following hypotheses.

1. Flight crews given the Flight Manual Bulletin will show less variability in method selection. The Bulletin describes methods for tasks needed to fly the Precision Descent using VNAV, making it more likely that flight crews will select this descent mode. These crews are also more likely to perform all activities needed for correct FMS configuration that are described in the Bulletin.

2. Flight crews given the Flight Manual Bulletin might show "better" performance during the first descent. Procedural recommendations contained in the Flight Manual Bulletin should simplify the task of constructing a plan for flying the Precision Descent, resulting in reduced time on task and less flight crew confusion. Tasks explicitly described in the Bulletin are less likely to be overlooked, misunderstood, or performed incorrectly. If procedure compliance tasks are problematic for flight crews (they may not be), the Bulletin could improve task performance. Performance differences should disappear as crews become familiar with the procedure.

3. Pilots may not need explicit procedural instruction for "correct" performance on the Precision Descent. Since the Precision Descent was not believed to introduce any new tasks for experienced crews, the statement of ATC requirements provided by the procedure Chart might be sufficient for acceptable performance. "Correct performance" consists in complying with all of the procedure requirements (described in Figure 5).

The next three factors suggest reasons for not relying upon the Flight Manual Bulletin for procedure introduction, though they were not hypotheses directly tested in this study.

The Bulletin may complicate performance by adding more to read during time critical descent planning. The Precision Descent clearance is issued only 2-4 minutes before descent will begin so that the latest possible trajectory advisory from the DA can be used. Crews may not have time to coordinate two pieces of reference material to plan their descent. Thus, instead of facilitating crew performance of a novel (but straightforward) procedure, the Bulletin may actually complicate it.

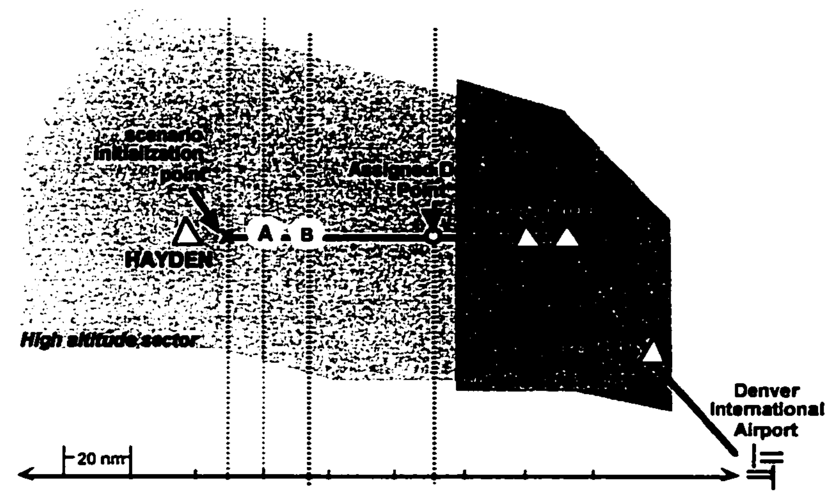
The Flight Manual Bulletin merely restates the procedure description in a different format. One could argue that the Bulletin's main value is that it restates the procedure's requirements in a different format. If this is true, there are probably better ways of providing this redundant information to flight crews.

Not all crews read Flight Manual Bulletins. Flight crews are required to carry their Jeppesen Procedure Manual and comply with its descriptions of ATC regulations and procedures. Use of Flight Manual Bulletin recommendations is optional, and our experience in the 1995 Field Evaluation suggests that they are not used by all flight crews.

DESIGN

Subjects

Eight 747-400 type-rated flight crews who fly for commercial air carriers were recruited to participate in the experiment. Participants were recruited by Bionetics Corporation, and were paid for their time and compensated for travel expenses.



A: Precision Descent Notification: *"UAL802, Expect Precision Descent."*

B: Precision Descent Clearance: *"UAL802, Cleared for Precision Descent at 27 miles west of Frogs, 300 knots."*

Figure 7. Scenario (run) #1 from Precision Descent simulator study.
The Notification was issued east of Hayden in order to reduce scenario time for the experiment; during normal operations this clearance would have been issued roughly 60 miles earlier. This should not have affected procedure performance during the simulator study because flight crew workload was low during this portion of the flight.

Experiment Scenarios and Clearances

Each flight crew flew eight Precision Descents in a Boeing 747-400 full-motion simulator. Figure 7 presents a typical scenario used in the evaluation. A different scenario was developed for each of the eight runs. Each one began in the late cruise phase of flight 90 miles west of FROGS and roughly 160 miles northwest of Denver International Airport.

Clearance phraseology and timing were scripted for each run. Scenario (run) order was the same for each crew. Eleven variables were manipulated to test the "robustness" of the procedure and its clearances under varying operational conditions. Tables 1 and 2 show the manipulations that were used for each scenario. These included clearance timing, lateral route, cruise altitude, assigned descent point location relative to VNAV top of descent, wind speed and direction, waypoint crossing speed, assigned descent speed, mid-descent "altitude hold" clearances, and mid-descent speed adjustments. Intermediate altitude clearances (Precision Descent clearances intended

Table 1

Scenario manipulations of descent context.

run	Cruise wind conditions	ADP to VNAV T/D separation (nm)[a]	Descent clearance timing (nm before ADP)	Excess energy[b]	Difficulty
1	light tailwind	-2	40	none	low
2	light tailwind	+2	20	none	moderate
3	strong tailwind	+8	20	high	moderate
4	strong tailwind	+8	20	very high	moderate
5	calm	-2	20	high	moderate
6	strong headwind	-2	20	high	moderate
7	strong tailwind	+8	20	very high	high
8	strong tailwind	-8	10	none	high

[a]A positive difference indicates that the assigned descent point (ADP) is *past* the VNAV top of descent (i.e., closer to the airport).
[b]'Energy' indicates the aircraft's excess energy during descent.

to clear an aircraft to a mid-descent altitude above the crossing altitude) were tested in runs #3, #4 and #5.

Scenario difficulty varied as a consequence of these combined manipulations. A second consequence was the energy status of the aircraft during the descent: delayed descent clearances or speed reductions during descent can cause the aircraft to have an excess of potential or kinetic energy that must be dissipated in order to meet the altitude and speed restrictions at the metering waypoint. An estimate of each run's difficulty level and its 'energy excess' is included in Table 1.

The scenarios were designed to be as realistic as possible, with an experienced air

Table 2

Scenario manipulations of Precision Descent clearances.

run	Assigned descent speed	Mid-descent Level-off	Descent speed change	Tomsn speed restr. canceled	Lateral route	Cruise alt. change	Int. alt. clearance[a]
1	300	no	-	no	default	no	no
2	.84/300	no	increase	yes	default	no	no
3	260	no	-	no	direct Tomsn	no	yes
4	300	yes	-	no	default	no	yes
5	340	no	-	no	direct Tomsn	no	yes
6	. 84/340	no	decrease	yes	direct Tomsn	no	no
7	. 84/340	yes	decrease	no	default	yes	no
8	. 82/300	yes	increase	no	direct Tomsn	no	no

[a]Two versions of the Intermediate Altitude Precision Descent Clearance were tested during runs 3, 4 and 5. A discussion of these differences, and their impact on crew performance is discussed in Crane et al. 1997.

traffic controller handling communications with the flight crew, and live background chatter on the air traffic radio frequency. Minor distractor tasks were scripted into each flight (flight attendent queries, traffic and weather advisories, simulated equipment failures) to manipulate workload during descent preparation. All but two of the runs were flown to landing. Although it was not necessary for data collection (since the Precision Descent ended at the metering waypoint), this was done to increase pilot workload and add to the realism of the simulation by requiring flight crews to prepare for approach and landing while flying the descent. Continuing the flight to landing also provided a fifteen minute interval of high workload after pilots passed the metering waypoint and before they began the next flight/run.

Procedure Documentation

This experiment compared a "Chart Only" minimum briefing condition with a second "Chart with Bulletin" condition similar to that used during the DA Field Evaluation. None of the crews received any additional training on the new procedure or its clearances.

Precision Descent Chart. All flight crews were given a Precision Descent Chart presenting ATC compliance requirements for the procedure. This Chart (Figure 4), modeled after the aviation charts published and distributed by Jeppesen-Sanderson Corporation, provides sample clearances for the procedure, describes their content and meaning, indicates where needed clearance information can be found (in published charts or verbal ATC communications), and states requirements for compliance with ATC expectations.

Precision Descent Flight Manual Bulletin. In addition to the Chart, four of the eight crews received a "Flight Manual Bulletin" containing method recommendations. The Bulletin (Figure 6), patterned after documents developed by United Airlines for their 747-400 fleet, essentially provides a procedure "recipe": aircraft-specific technique suggestions for performing tasks required by the Precision Descent.

Other documents provided to all flight crews included a TOMSN/RAMMS1 Arrival chart, ILS08 and ILS35/CAT II approach plates, and a flight plan with descent forecast winds and ATIS information for each flight ("ATIS" is an acronym for "Automatic Terminal Information Service"; a recorded radio message that provides current information about weather and airport conditions).

Flight crews received no feedback on their performance during the experiment, since task performance and skill development in the absence of feedback more closely represents what would occur in an operational setting.

Data

The following data were gathered during each of the 64 descents.

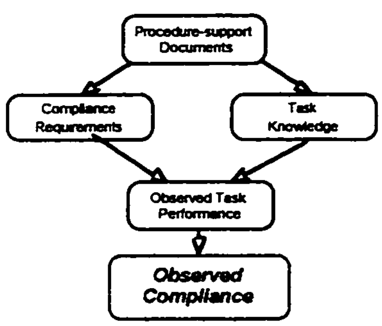
Videotape. Each descent was videotaped. Four cameras were positioned to show 1) an overview of the cockpit, 2) the captain's CDU, 3) the first officer's CDU, 4) the captain's Nav Display. The audio record included the cockpit and all ATC radio communications.

Digital simulator data. Over 100 simulator variables were monitored during the flight. State data (e.g., airspeed, altitude, heading, longitude) were recorded continuously at 1 hertz, and pilot actions and other discrete events (button presses, autoflight mode changes) were recorded when they occurred.

Pilot questionnaires and interviews. At the end of the day, each pilot completed a questionnaire designed to assess 1) the procedure's acceptability to pilots, and 2) the perceived difficulty of the procedure and its clearances (Appendix A). The crew was interviewed informally by the researchers after completing the questionnaires.

Performance measures. Measures of crew compliance with the six Precision Descent requirements described in Figure 5 were obtained for each flight from an analysis of its digital data and video records. Deviation from charted compliance requirements were identified. The requirements were strictly applied in making these deviation measurements; for example, descent initiation six miles from the ADP (one mile outside of the charted tolerance), or descent speed 11 knots different from the ADS both counted as "compliance errors." One of the compliance requirements was that the flight crew maintain cruise airspeed until reaching the Assigned Descent Point (compliance measure #1). There was no published tolerance that could be used to measure deviation from this requirement. Therefore, any crew activity after the descent clearance was issued that resulted in a cruise airspeed change before the aircraft reached the ADP was counted as an error. The speed changes resulting from these actions were as small as four knots.

RESULTS: PRODUCT ANALYSIS OF EXPERIMENTAL DATA



Procedure Compliance

Compliance errors by run. The impact of scenario manipulations on procedure compliance are shown in Table 3. These effects are discussed at length in Crane et al. (1997). Two of these scenario effects on compliance will be discussed here because they affect our comparison of training methods.

Table 3

Scenario Differences in Observed Precision Descent Compliance Errors (in percent)

run	(1)speed change in cruise	(2)ATC not notified	(3)descent out of range	(4)descent speed out of tolerance	(5)too fast at TOMSN	(6)too high at TOMSN
1	12.5	-	0	62.5	62.5	0
2	25.0	-	12.5	25.0	-	12.5
3	12.5	62.5	12.5	12.5	12.5	12.5
4	50.0	50.0	12.5	12.5	25.0	37.5
5	0	-	12.5	0	12.5	0
6	37.5	-	14.3	12.5	-	25.0
7	0	50.0	0	25.0	75.0	37.5
8	0	37.5	0	0	12.5	12.5

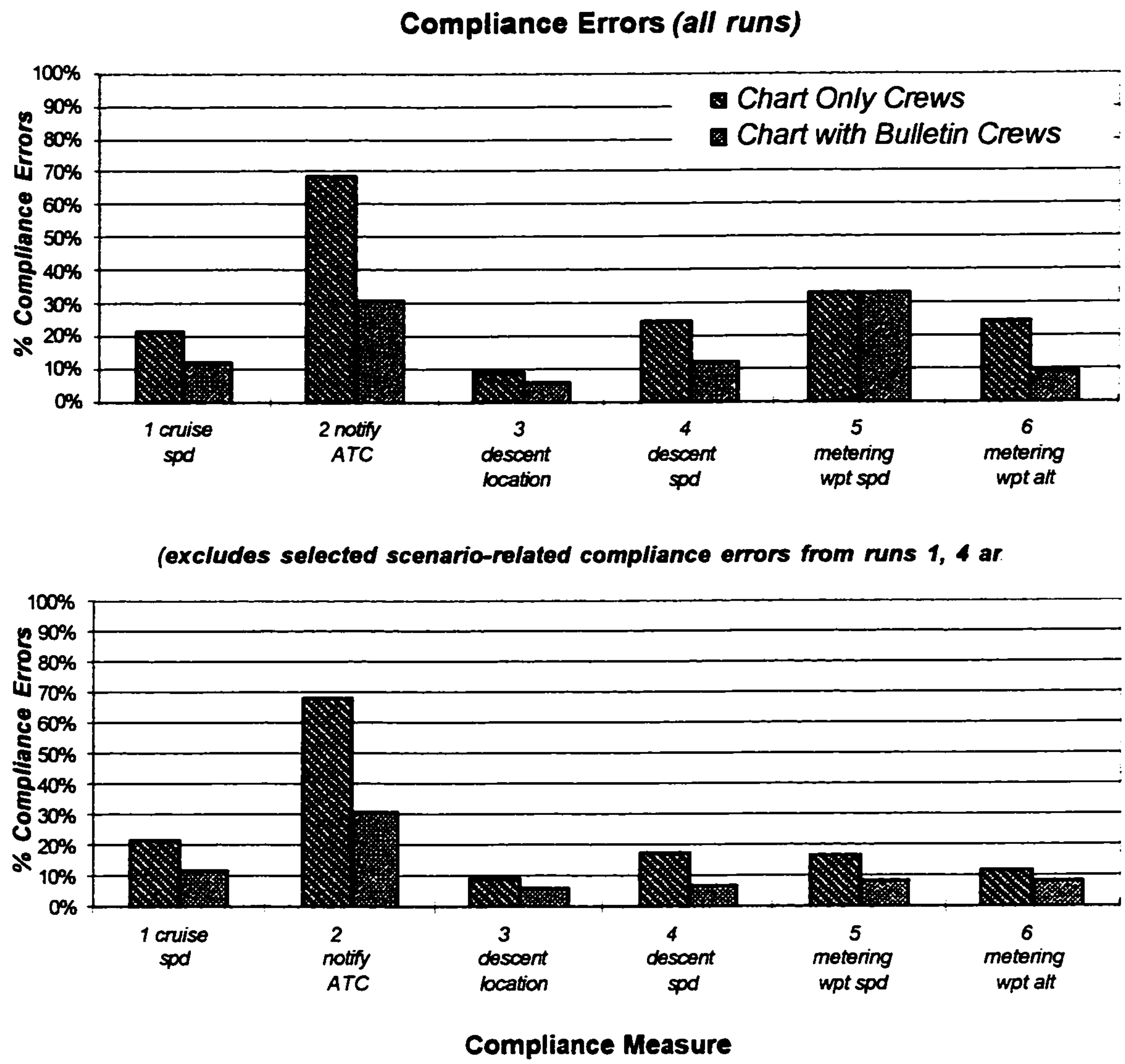
With two notable exceptions, crew performance on the first run was excellent: no readback errors were observed, and compliance was near perfect. The exceptions were the high incidence of deviations from the descent speed and metering waypoint speed restrictions. Recorded cockpit discussions during this descent suggest that these speed violations occurred because flight crews were testing the ability of the simulator's VNAV to acquire these speed targets and not because they were unaware of the restrictions. No between-condition differences in compliance were found during this run.

High excess energy during descent in runs #4 and #7 appeared to reduce the flight crews' ability to comply with the metering waypoint speed and altitude restrictions. Scenario manipulations tested in these runs (including artificially delayed ADP locations, mid-descent level-off clearances, and assigned speed reductions during descent) caused the aircraft to be high on its descent profile, so that the assigned speed and altitude restrictions at TOMSN could not be met without using speed brakes. Because scenario manipulations reduced crew compliance with these restrictions, and run order affected compliance with the speed restrictions on run #1, these errors were excluded from the subsequent analyses of the effect of training condition on compliance (Figure 8).

Compliance errors by training condition. After excluding scenario-related compliance errors, comparison between the two training conditions showed that flight crews in the "Chart with Bulletin" condition made fewer compliance errors on all six measures (Figure 6). A 2 (condition) x 6 (measure) analysis of variance with replication found significant main effects of both training condition [$F(1,275) = 6.31$, $p < .05$] and measure [$F(5,275) = 7.17$, $p < .01$]: use of a procedure Bulletin with the Precision Descent Chart was associated with reductions in procedure compliance errors, and the number of compliance errors varied between measures. There was no significant interaction observed between measure and training condition; bulletin-related improvements in compliance appeared to be consistent across measures.

ATC Communications

The "Chart with Bulletin" group required less time to complete ATC communications, and made fewer requests for clearance or procedure clarification. Fewer readback errors were observed in the "Chart Only" condition. Table 4 presents measures related to flight crew communication with air traffic control that were obtained from 6 of the 8 simulator runs.



1 Maintain cruise Mach or airspeed until reaching the ADP.
2 Inform ATC if the VNAV T/D is more than 5nm from the ADP.
3 Initiate descent within 5nm of the ADP.
4 Maintain assigned Descent Speed within 10 knots.
5 Cross the metering waypoint at the charted speed restriction.
6 Cross the metering waypoint at the charted altitude restriction.

Figure 8. Compliance with charted requirements, by training condition. Scenario-related compliance errors from runs #1, #4 and #7 were excluded from the lower bar graph. These include the descent speed and metering waypoint speed deviations that were observed during run #1, and the metering waypoint altitude and airspeed deviations observed during runs #4 and #7.

Table 4

Precision Descent Clearance Measures

run	condition*	Descent Clearance type	T_{total}** (seconds)	SD_T (seconds)	Readback Errors	Incomplete Readbacks	"clarify" or "repeat" requests	"unable to make crossing restriction"
1	B	normal	18.5	7.00	0	0	2	0
1	C	normal	19.5	4.04	0	0	3	1
2	B	normal	25.0	16.06	1	1	1	0
2	C	normal	21.5	1.73	1	0	1	0
3	B	int. altitude	31.25	15.84	1	2	3	0
3	C	int. altitude	45.5	34.28	0	2	4	1
4	B	int. altitude	30.0	11.92	1	0	1	0
4	C	int. altitude	34.75	16.96	0	2	1	2
6	B	normal	24.0	6.22	1	1	2	0
6	C	normal	25.25	4.43	0	2	3	0
8	B	normal	20.5	3.42	0	1	2	0
8	C	normal	24.5	4.12	0	0	2	0
ALL	B	-	24.88	10.96	4	5	11	0
ALL	C	-	28.50	16.80	1	6	14	4
1,2,6,8	ALL	normal	22.34	6.81	3	5		
3, 4	ALL	int. altitude	35.38	19.84	2	6		

*condition: B: "Bulletin-with-Chart" condition; C: "Chart Only" condition

**Ttotal: Elapsed time from ATC-initiated contact to final crew acknowledgement of clearance.

Table 5

TOMSN Arrival Times for scenarios using default TOMSN1 Lateral Route

run	condition	T_{TOMSN}* (seconds)	SD_T (seconds)	Mach/IAS	descent speed change	mid-descent level-offs)
1	B	806.75	4.11	-	-	-
1	C	830.00	12.01	-	-	-
2	B	795.25	3.50	.84/300	300->340	-
2	C	796.50	2.08	.84/300	300->340	-
4	B	709.5	8.58	-	-	FL270
4	C	698.25	5.91	-	-	FL270
8	B	709.00	18.99	.84/340	340->300	FL260
8	C	713.00	10.75	.84/340	340->300	FL260

*Elapsed time for aircraft to travel from 80nm West of FROGS to TOMSN.

TOMSN "Arrival Times"

In the two CTAS/DA Field Evaluations, the average error and standard deviation between DA-predicted and actual metering waypoint arrival times for FMS-equipped aircraft was -2.5 +/- 10.0 seconds in 1994 and -3.1 +/- 11.0 seconds in 1995 (Green, Vivona & Sanford, 1995; Green & Vivona, 1996). This error was determined from an arrival time prediction made by the Descent Advisor when the aircraft was approximately 100 miles west of the metering waypoint. In the present study, the elapsed time to fly from 80 miles west of FROGS to TOMSN (a distance of 120 miles) was measured for each aircraft to estimate the variability of arrival times due to crew performance differences alone; within each scenario, all other factors (winds, clearance parameters and lateral route) were held constant. Essentially no difference was observed in this measure between the two briefing conditions (Table 5).

Questionnaire Results

A post-experiment questionnaire obtained pilot evaluations of the procedure's difficulty, acceptability, and the clarity of its clearances and requirement statements. The "Chart with Bulletin" group found the procedure less difficult, less confusing, and more acceptable than the "Chart Only" group. Appendix A presents the questionnaire data; these results are discussed further in Crane et al. (1997).

DISCUSSION

"Product" Measures

Our initial hypotheses about flight crew performance of the Precision Descent proved incorrect on a number of counts. Though both groups performed well on the first run (a normal Precision Descent scenario with ample time for crews to prepare for descent), compliance was poorer on the later scenarios.

The Bulletin and procedure compliance. Contrary to our expectation, the Bulletin was related to significantly improved procedure compliance on these later runs, with overall improved performance observed in the "Chart with Bulletin" group on all six measures. Over one third of observed deviations from the assigned descent speed and the metering waypoint airspeed restriction occurred on the first descent, and appeared to be experiment-related artifacts (i.e., flight crews were assessing the VNAV performance of the simulator). Nearly two thirds of the remaining waypoint crossing restriction violations occurred during runs 4 and 7, the two highest energy descents. After these scenario-related compliance errors were excluded from the analysis, compliance with the assigned descent location, assigned descent speed, metering waypoint speed restriction, and metering waypoint altitude restriction was better than 80% in the "Chart Only" condition, and better than 90% in the "Chart with Bulletin" condition. Compliance with measure #1 (maintain cruise airspeed until reaching the assigned descent point), and measure #2 (notify ATC if the VNAV T/D is out of range) was better than 75% in the "Chart with Bulletin" condition. The Bulletin reduced but did not eliminate compliance errors, and room still exists for improvements in crew performance, especially on measure #1.

The Bulletin and procedure understanding. Data from Pilot Questionnaires and ATC transcripts suggest that the Bulletin improved pilot understanding of the procedure. Questionnaire data shows that crews with the Bulletin rated the procedure and its clearances more favorably, found them less confusing, and felt that less training was needed for the procedure. Objective measures -- reduced time for Precision Descent clearance communication, reduced number of crew requests for ATC to clarify the procedure or clearances -- support the pilots' subjective assessment.

The Need for Further Analysis

The results show improved compliance, reduced number and length of ATC communications, and more favorable reactions to the procedure in the "Chart with Bulletin" group. However, more information about how the Bulletin improved crew understanding and performance is needed before changes can be made to the procedure and its documents. Among the questions that remain are:

- How did the Bulletin affect flight crew execution of procedure related tasks?
- Why was poor compliance observed in both groups with cruise airspeed?
- Why did the "Chart with Bulletin" group comply better with compliance measure #2 (notify ATC if the VNAV T/D is out of range)?

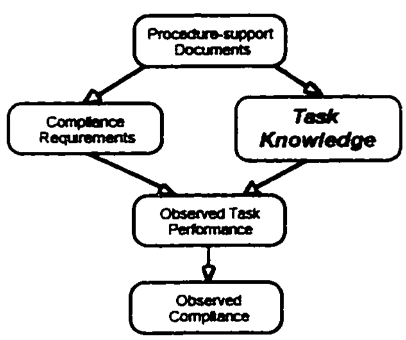
A task model describing activities that must be performed by crews to fly the Precision Descent was used as a framework for addressing these questions. This model was used to determine the relationship between the activities that it represents and the information provided in procedure documents. Establishing the relationship between procedure tasks, requirements and support documents provided a means to explain how these documents influenced observed flight crew performance of the procedure.

CHAPTER 4:

A Model-Based Evaluation of the Precision Descent

This chapter describes four model-based analyses: 1) development of a Precision Descent task model, 2) a content analysis of Precision Descent documents, 3) an "overlay" analysis identifying task and procedure elements explicitly described in those documents, and 4) a process analysis of methods used by flight crews to comply with the procedure.

TASK MODEL



Related Research

A framework was developed by Mitchell and her colleagues to model activities performed by human operators in the control of complex dynamic systems. The Operator Function Model (OFM) is a hierarchically organized description of operator activity. The hierarchy structure represents operational functions at the top level, proceeds down through their component tasks and subtasks, ending with individual operator actions at the leaf nodes. This structure supports inference of operator activity based on the current state of a controlled system and a limited set of observable actions (Chu et al. 1993; Mitchell, 1997).

The OFM framework was used by Callantine to model pilot interactions with cockpit automation. The Georgia Tech Crew Activity Tracking System (GT-CATS, or CATS) uses a modified OFM to describe and predict flight crew activity in Boeing-757/767 and Boeing 747-400 cockpits (Callantine et al. 1996, 1997b). CATS predicts pilot activity related to the use of the aircraft's flight control systems. It was designed to perform operator tracking and to provide the activity knowledge needed for an intelligent aiding and advisory system. This work provided an example of a modelling framework appropriate for describing the Precision Descent flight crew activities.

Riesbeck and Hutchins (1982) developed a model of activity for solution of a marine navigation problem, and used it to demonstrate how a model-based representation can support evaluation of procedure structure. A dependency analysis of the activity model identified constraints on task order inherent to the problem itself. These constraints defined a set of possible procedures (step sequences) that would lead to a correct solution. The nested goal-subgoal-action hierarchy structure for each of these procedures was described. Goal-action sequences were used to represent the temporal ordering of task goals and their associated actions as the procedure was performed. Criteria were applied for procedure evaluation that were based on ideas about how this goal-action structure could affect ease of learning and reliability of task performance.

Structure and Content of Task Model

The Precision Descent task model's structure and content were influenced by the work of Mitchell and Callantine. Its content was also influenced by the work of Riesbeck and Hutchins. It differs slightly from the OFM framework, primarily in the specificity of its description of operator activity. Because the Operator Function Model was designed to provide a framework for monitoring and interpreting operator activity, its description of activity needed to extend to the level of machine-observable operator actions. The lowest level of activity described in the current model is variable, determined by 1) the need to adequately represent the documents' descriptions of tasks, and 2) the level of specificity needed to identify potential operator errors and significant method differences.

A second difference is in the Precision Descent task model's organizational hierarchy. The top level of its hierarchy (shown in Figure 9) represents groups of tasks spaced closely in time that support a high-level goal appropriate to that stage in the descent. The next level in the hierarchy represents sets of tasks that accomplish a specific function. Figure 10 shows a brief excerpt from the task model's description of descent preparation activities, and Figure 11 uses the Precision Descent timeline to illustrate that portion of the model. The full task model can be found in Appendix B.

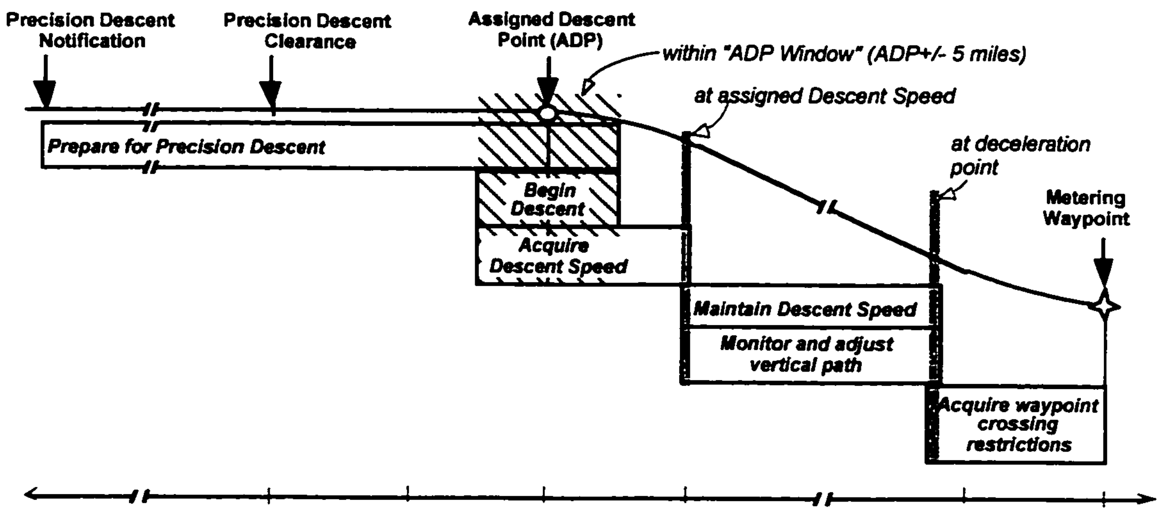


Figure 9. Timeline representing top level of Precision Descent task model hierarchy.

Task Activity	*Condition*	*Data needed, source*	*Timing: after...*	*until...*
I. Prepare for Precision Descent	notified to "expect Precision Descent"		Precision Descent Notification	
A. Configure VNAV				
1. enter descent forecast winds	data available	descent winds, altitudes source: ACARS dest.: DES Frcst. Page		
2. enter crossing restriction (at meter fix)	metering waypoint known	metering wpt. crossing restriction source: Chart dest: LEGS page		
3. enter descent speed in FMS	data available	assigned descent speed source: Prec. Descent Clearance dest: DES page	Precision Descent Clearance	
B. Configure MCP/Enable Descent	cleared for descent			
...				
C. Determine where to descend	data available (Precision Descent Clearance)		Precision Descent Clearance	
1. configure ADP	time available	Assigned Descent Point source: Prec. Descent Clearance		
a) Method 1: configure ADP as user-defined wpt		dest: LEGS page		
b) Method 2: configure ADP fix circle		dest: FIX page		
2. determine a/c position relative to ADP		Assigned Descent Point source: Prec. Descent Clearance		
a) Method 1: monitor ADP on PROG page				
b) Method 2: monitor ADP on Nav Display	ADP fix circle programmed (or) ADP waypoint programmed			
3. determine if T/D is within 5nm of ADP	VNAV programmed for Precision Descent	Assigned Descent Point (ADP) Assigned Descent Speed source: Prec. Descent Clearance ADP tolerance(=5nm) source: Chart		
a) Method 1: use PROG page information				
b) Method 2: use Nav Display	fix circles programmed			
4. choose descent location	T/D is within 5nm of ADP			

Figure 10. Descent preparation activities, from the Precision Descent task model (Appendix B).

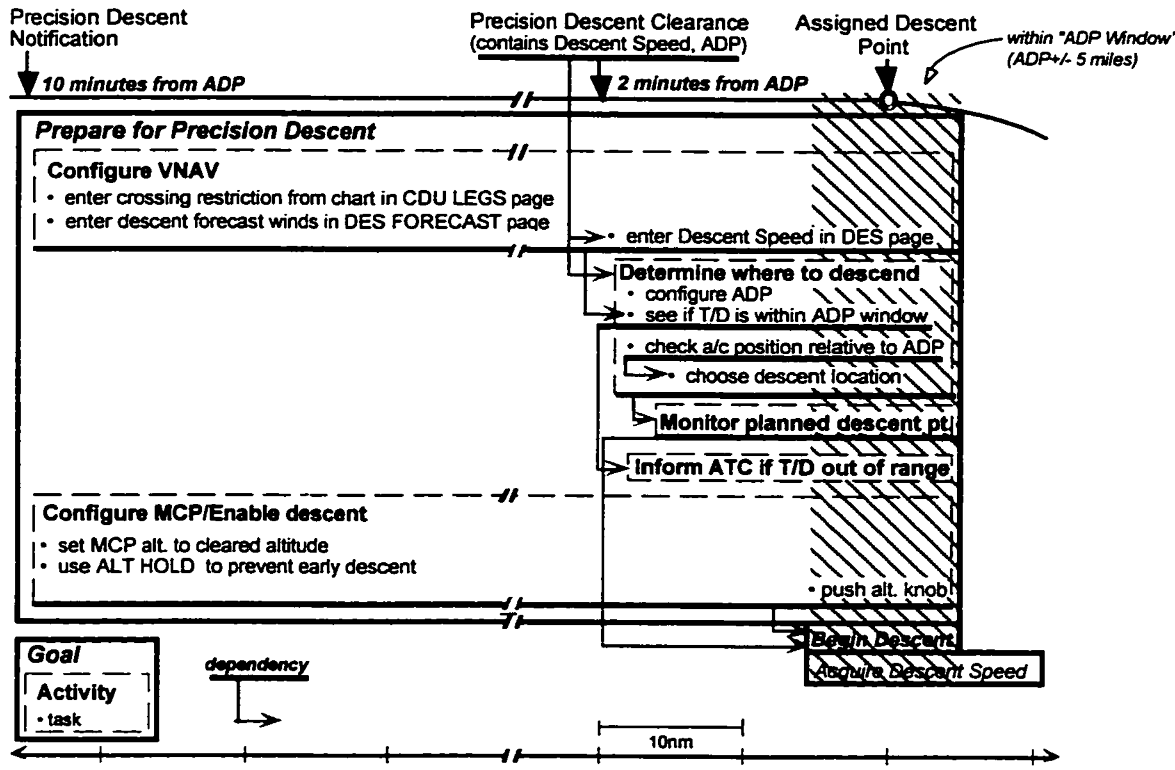


Figure 11. Precision Descent timeline, showing the "Prepare for Precision Descent" activities from the task model. Nested boxes represent the model's hierarchical organization of task activity, with the sides of each box indicating when the activities it contains can be performed. Solid arrows indicate the location of Precision Descent events, and barbed arrows represent task dependencies -- on clearance information, or on completion of other tasks.

Task Characteristics

The model explicitly represents many of the procedure characteristics that constrain task performance. These include task order dependencies, information requirements, and the window of time for correct performance. Particular tasks that might represent weak points in the procedure were identified from inspection of the model's representation of these characteristics.

Unfamiliar activities. Some of the higher-level tasks represented in the Precision Descent model were known to be unfamiliar to flight crews. An example of one of these novel tasks is "I.C.3: determine if T/D is within 5 nautical miles of ADP," a task that involved determining the distance between the T/D (VNAV-calculated Top-of-Descent point) and the ADP (Assigned Descent Point). If the T/D and ADP are within 5 miles of each other, VNAV can be used to begin the descent; otherwise the crew is told to "inform ATC..." (compliance measure #2). Few ATC procedures assign a specific descent location in advance, and none ask for comparison between a specific location and the VNAV T/D, so this is a new operation for flight crews. Nevertheless, experienced pilots are familiar with methods for performing this comparison, so a detailed description of methods should be unnecessar and a clear statement indicating the need for the comparison sufficient for satisfactory performance.

This was the rationale for the "Chart Only" method of procedure introduction; pilot "how-to-do-it" knowledge of methods for procedure tasks was believed to be complete. There was one instance where this assumption proved invalid. As discussed by Crane et al. (1997), some pilots were unaware that a "Mach/IAS" value (a combined Mach and airspeed, e.g. ".84/300") was a valid speed entry in the CDU's descent page, which led them to use incorrect methods for handling this two-value speed assignment.

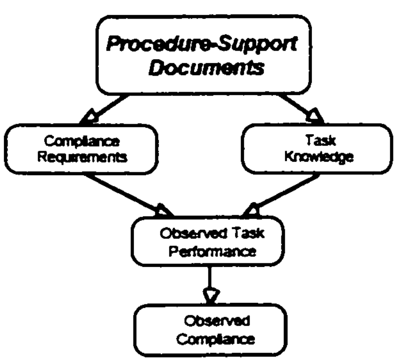
Alternative methods for task performance. The model represents different methods for accomplishing procedure tasks, and includes all of the correct methods used by flight crews during the experiment. Method differences could have contributed to observed between-group differences in compliance; the earlier discussion of tradeoffs between use of FLCH and VNAV descent modes illustrates how this could happen. Method alternatives also exist for monitoring the aircraft's approach to the ADP and for adjusting descent rate and airspeed.

Task dependencies. This analysis shows dependencies that constrain the order and timing of task performance. Some information dependencies make completion of a task impossible until its preconditions have been met; for example, VNAV configuration can begin as soon as the Notification Clearance is received, but cannot be completed until the assigned descent speed is known (after the Precision Descent clearance; see Figure 11). Other tasks are not constrained, but still must be performed in a particular order: if the VNAV T/D is compared to the ADP before descent speed and crossing restrictions have been entered into the FMS (i.e., before VNAV is configured for the Precision Descent) the comparison is invalid, but nothing prevents these tasks from being performed out of order. These are instances of two task structure problems that Riesbeck and Hutchins warn may lead to performance errors (1982).

Temporal aspects of task performance. Another problem is the number of tasks that must be performed after the Precision Descent Clearance is issued and before the aircraft reaches the Assigned Descent Point. As Figure 11 illustrates, the tasks "enter Descent Speed in DES page", "configure ADP", "see if T/D is within ADP window", "check aircraft position relative to ADP", "choose descent location", and more all must be completed within a two to three minute interval (Figure 11).

Information provided by the Chart and Bulletin should influence task timing and methods, increasing the likelihood that tasks are performed efficiently and correctly. The content analysis identifies information in both documents that could influence task performance, and describes how that information is organized and presented.

CONTENT ANALYSIS OF DOCUMENTS



Rationale

The purpose of this analysis was to obtain thorough descriptions of information contained in the Chart and the Bulletin in order to determine how they could affect flight crew performance of the Precision Descent. Informational content was represented in a format that could be systematically compared to descriptions of the procedure's compliance requirements and tasks. The comparison identified procedure compliance and task-relevant information provided in the two documents.

Note that the document descriptions of procedure tasks and compliance requirements is incomplete. These documents represent only one source of task-relevant information; ATC clearances, the flight crew's knowledge about coordination of flight path with ATC, and their knowledge of the task environment complete the picture.

Related research. Mayer (1985), and Bovair and Kieras (1985) present methods for systematically determining the semantic content of explanatory text. Mayer performed analyses of scientific instructional text in order to test for a relationship between its explanatory content and the support it provided for problem solving. Bovair and Kieras used propositional descriptions of prose material to evaluate reader comprehension and recall ability, and to study acquisition of procedural knowledge from text (Bovair & Kieras, 1985; Kieras & Bovair, 1986).

Method used to Analyze Procedure Documents

Each document was divided into sections, and the information contained in each of these sections was identified and added to a list of "idea units". These idea units are comparable in grain size to the propositional elements in the methodology described by Bovair and Kieras (1985). Instead of using their formal propositional representations, however, we chose (when possible) to list these units of information as direct quotations from the documents, an approach used by Mayer in his analysis of scientific prose (1985). We found this format for representing document content easier and more readable, and it provided the information needed for our analysis. Information that was provided graphically or was clearly implied by the document's explicit content was also included in these lists, accompanied by a brief description of how it was presented. Figure 12 shows a portion of this content analysis, and Appendix C presents the complete analysis, including: 1) summary statistics about the amount and type of information each document provided; 2) lists of idea units for each document; 3) a table containing an illustration of each document section, the section's set of idea units, and their classifications.

Classification of Idea Units

Idea units were classified according to three information categories:

1. ATC procedure information category. Information that supports understanding of the Precision Descent procedure could match one or more of the following categories:

- procedure applicability -- who the procedure may affect

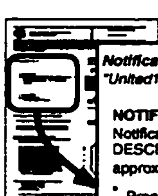
- what to expect -- what to expect during procedure; "heads up" notices
- compliance target source -- where to find procedure compliance target values
- compliance target usage -- how to interpret and apply those target values
- compliance target value -- specific targets (i.e., "340 knots")
- CTAS concept -- Precision Descent background information
- document content -- describes/clarifies chart or bulletin contents.

2. ***Procedure compliance measure.*** Notes the specific compliance requirements (if any) that the idea unit supports.

PRECISION DESCENT CLEARANCES

PRECISION DESCENT Notification: *"Company123, expect PRECISION descent."*
PRECISION DESCENT Clearance: (Issued approximately 2 minutes before the assigned descent point.)
"Company123, cleared for the PRECISION descent at ___nm E/W of ___ (fix),___knots."

Information	*procedure info. category*	*compliance requirement*	*task info. category*
C10. There are two Precision Descent Clearances. *(inferred from section content)*	what to expect	-	
C11. Precision Descent Notification will be given by controller. *(inferred)*	what to expect	-	
C12. "PRECISION DESCENT Notification:" [phraseology is] *"Company 123, expect PRECISION DESCENT."*	what to expect	-	
C13. "PRECISION DESCENT Clearance:" [phraseology is] ... *"Company 123, cleared for the PRECISION DESCENT at __nm E/W of __(fix), __knots."*	compliance target source	descent location, descent speed	
C14.			



Notification:
"United123, expect PRECISION DESCENT."

NOTIFICATION
Notification to expect the PRECISION DESCENT clearance will be received approximately 10 minutes before descent.

- Prepare to comply by entering the crossing restriction from the PRECISION DESCENT PLATE in the CDU LEGS page.

FORECAST WINDS
Descent forecast winds may be provided to the aircraft by ATC. If descent forecast winds are provided:

- Enter in the DES FORECAST page.

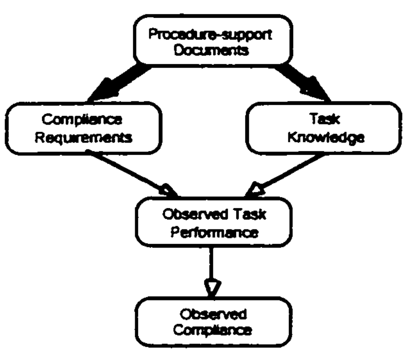
Information	*procedure info. category*	*compliance requirement*	*task info. category*
B19. "Notification to expect the Precision Descent Clearance will be received..."	what to expect		
B20. "...approximately 10 minutes before descent."	what to expect		
B21. [after Notification...]			task timing,
B22. "• Prepare to comply..."			task purpose
B23. "...by entering crossing restriction ...in CDU LEGS page."			task method
B24. "...crossing restriction from PRECISION DESCENT PLATE..."	compliance target source		task target
B25. "Descent forecast winds may be provided..."	what to expect		task target
B26. " ...by ATC."	CTAS concept		

Figure 12. Excerpts from the content analysis of the Chart (top), and the Bulletin (bottom). Document sections were analyzed for their informational content. Each item was then categorized by 1) "procedure information category" (what kind of information it provided about the ATC procedure); 2) "compliance requirement" (what compliance measure it related to); and 3) "task information category" (what kind of task information it provided). Blank cells in the table indicate no information in the relevant category. The full analysis of both documents can be found in Appendix C.

3. ***Task information category.*** Information regarding one or more of the following aspects of a procedure-related task:

- method description -- how to perform a task required by the procedure
- information identity -- key information required for task performance
- information source -- where key task information can be found
- information destination -- where the information must be entered
- task timing -- when a specific task should be performed
- task condition -- conditions for performing a task or choosing a method.

RELATIONSHIP OF DOCUMENT CONTENT TO PROCEDURE REQUIREMENTS AND TASKS

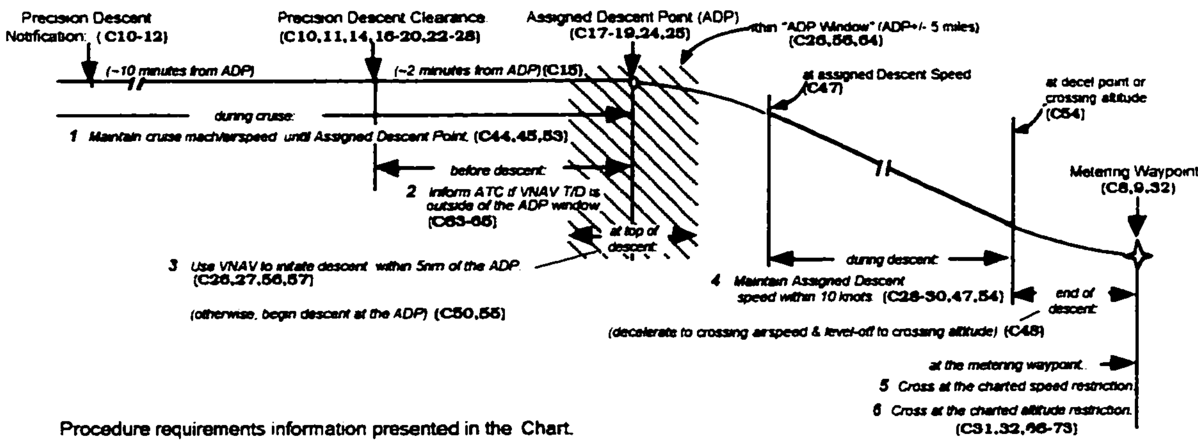


Rationale

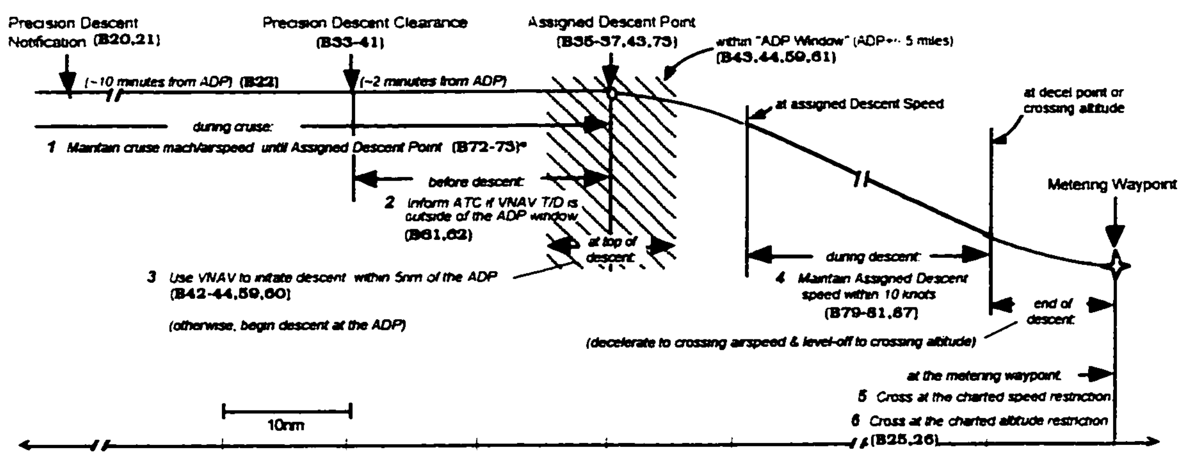
"Overlay" analyses were used to determine exactly what information the documents contained that could directly support flight crew performance of the procedure. Each idea unit was compared with the procedure-relevant concepts represented in the Precision Descent task model and with a statement of the Precision Descent compliance requirements. When a reasonable match was found, the task model and the statement of procedure compliance requirements were annotated with references to the document's representation of that concept. These annotated descriptions provided an index that showed precisely what procedure-related information was contained in the Chart and the Bulletin, and where and how that information was represented.

Compliance Requirements

The content analysis of the two documents was used to determine procedure compliance information represented in the Chart and the Bulletin. As expected, the Chart provided a complete description of procedure compliance requirements, including a full explanation of its airspeed and altitude targets, tolerances on airspeed and descent location, clearance content, and the meaning and application of clearance parameters. Much of the information was presented in both text and graphical format. The Bulletin added no new compliance information. The compliance information it did provide was embedded in its more narrative descriptions of procedure-related events, tasks and methods. Figure 13 shows that all of the Precision Descent's compliance requirements are described in the Chart, and many are repeated in the Bulletin. Numbers in the figure reference the two lists of idea units that can be found in Appendix C.



Procedure requirements information presented in the Chart.



Procedure requirements information presented in the Bulletin.

*B72-73: "Begin deceleration...after reaching the assigned descent point."

Figure 13. Precision Descent compliance requirements described in the Chart (above) and the Bulletin (below). The numbered subscripts attached to each highlighted element reference the specific item in the lists of the Chart's and the Bulletin's content found in Appendix C.

Both documents describe poorly the requirement to maintain cruise airspeed until reaching the ADP. The Chart presents this requirement only as part of the vertical profile graphic, and does not include it in the text description of the "Precision Descent Procedure." The Bulletin states that crews should "begin deceleration after reaching the assigned descent point" when the assigned descent speed is slower than the cruise airspeed (Figure 13), but does not make any statement about when to accelerate if a speed increase is needed. Inadequate representation of this requirement in both documents could account for the poor compliance observed during the simulator study. Note that if an analytical method had been used to insure that the documents fully described the procedure requirements these problems might have been noticed before the evaluation. It's not certain this would have occurred, however, because the experimental data helped focus the analysis on known performance problems in the present study.

Document Content and Precision Descent Tasks

Both the Chart and the Bulletin provide information describing task activities; however, neither provides a complete description of all procedure tasks. The task model was annotated with references to task-relevant information represented in either document. This annotated model can be found in Appendix D. Figure 14 illustrates a portion of this model graphically, showing the difference between information provided in the two documents about descent preparation activities. The Bulletin provides more information about task dependencies and more cues that can organize task performance. An example of these cues includes a description of tasks to be performed following the Precision Descent Notification ("enter crossing restriction..." [and] "enter descent winds...") and the sequence of tasks that should follow the Precision Descent Clearance ("enter descent speed..." [then] "see if T/D is within ADP window"; [if not] "notify ATC.").

The two documents differed in their presentation of the instruction that flight crews notify ATC if the VNAV T/D is more than 5 miles from the ADP. Both documents make

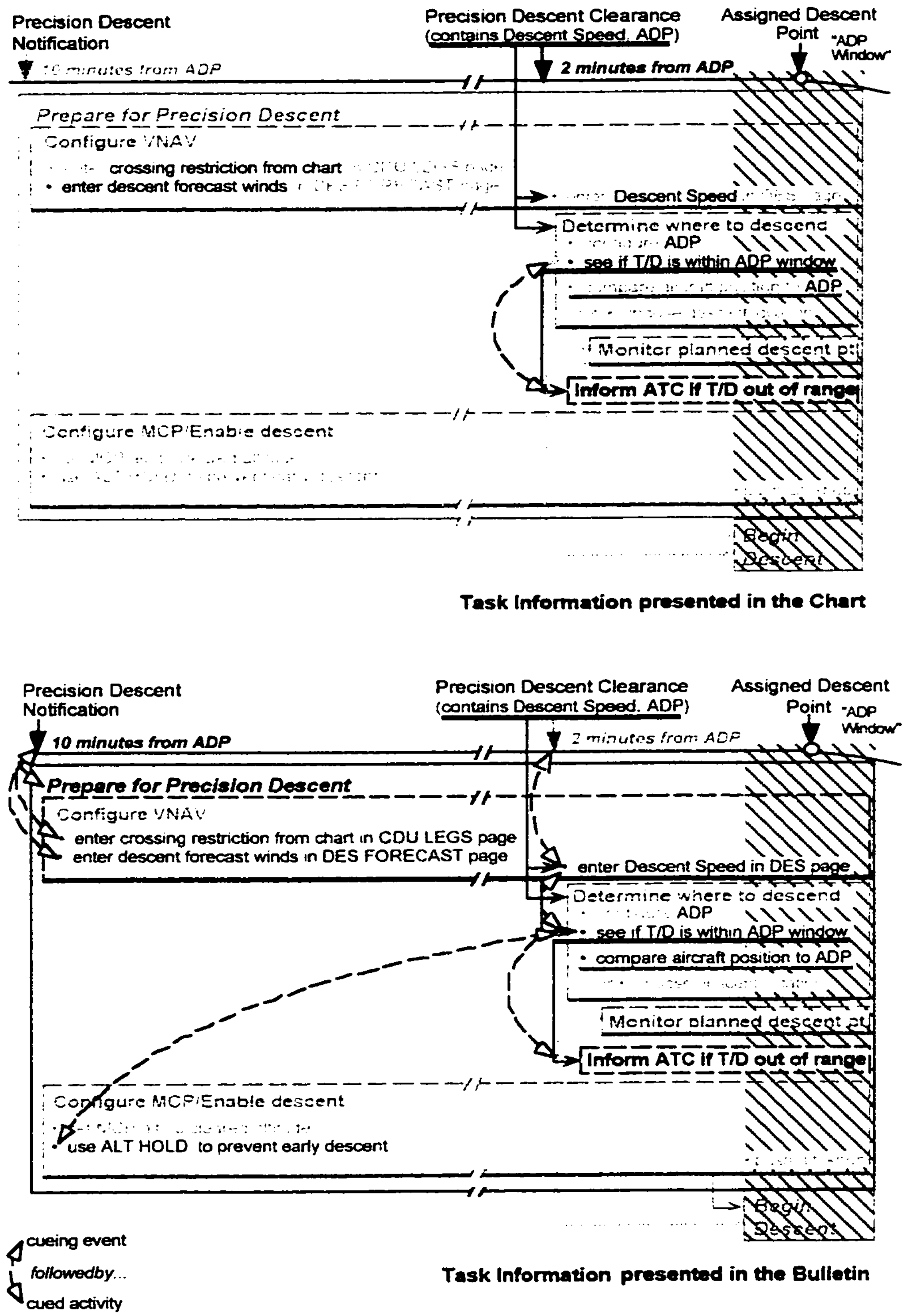


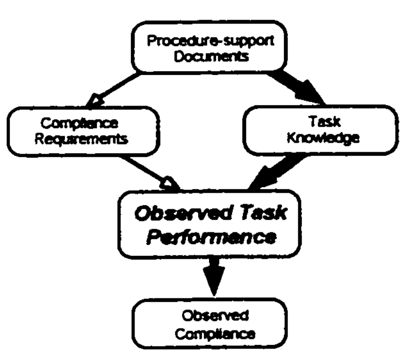
Figure 14. "Prepare for Precision Descent" activities with task information from Chart and Bulletin shown. Task information provided in the Chart is shown in the diagram above: task information from the Bulletin is shown below. Portions of the model that are described in the documents are represented in color; model elements that are not described are "grayed out." Dashed arrows indicate document descriptions of when a specific task should be performed, linking specific events or activities to the actions that should follow them.

this statement explicitly, and the Chart presents it as part of a published procedure (which should carry more weight than the Bulletin's "technique recommendations"). In the simulator study, however, markedly better compliance with this requirement was observed in the "Chart with Bulletin" group (Figure 8). The Bulletin presents the "Inform ATC..." task as part of an integrated sequence of activities that follow the Precision Descent Clearance. The Chart describes the condition for performing this task ("If the VNAV T/D is more than 5 nm from the ADP...") but does not integrate it into the larger set of actions to be performed in the short period of time before descent initiation. Additionally, this information is presented as a note on the vertical profile graphic, and not included in the text description of the "Precision Descent Procedure."

The Bulletin also provides a more detailed description of task activities. For example, while the Chart suggests entering descent forecast winds in the FMS, the Bulletin describes entering the information on the CDU's DES Forecast Page after ATC has issued the Precision Descent Notification.

This analysis of the relationship between document content and procedure tasks showed that the Bulletin presents task sequences and cues for task performance that are absent from the Chart. It also provides more method descriptions, and more detailed method descriptions than the Chart. The next section explores specific questions about the Bulletin's effect on descent preparation task performance.

PROCESS ANALYSIS OF SIMULATOR DATA



Bulletin Content and Task Performance

A limited process analysis of the simulator data was used to investigate whether improved compliance might result from Bulletin-related differences in flight crew use and configuration of VNAV. Analysis of all possible document-related differences in task performance is beyond the scope of this thesis. However, this limited analysis demonstrates how this method improved our understanding of the Bulletin's influence on task performance and procedure compliance.

The following questions address performance of VNAV configuration that were described in the Bulletin (Figures 6, 14). They represent opportunities for between-group differences in VNAV usage to occur, and for a pattern of differences related to Bulletin content to become apparent.

1. *Did the crew use VNAV to initiate the descent?*

   If VNAV was used was it configured properly? i.e.,

2. *Was the crossing restriction entered properly in the FMS?*
3. *When was this done (relative to descent clearances, beginning of descent)?*
4. *Were descent forecast winds entered properly in the DES Forecast Page?*
5. *When were the winds entered (relative to clearances, and the beginning of descent)?*
6. *Was descent speed entered properly in the FMS?*
7. *When was it entered (relative to clearances, beginning of descent)?*
8. *Was Altitude Hold used to prevent an early VNAV descent?*

Process Measures

The Crew Activity Tracking System (CATS) was used to obtain process measures from the recorded simulator data that answered the questions listed above. Callantine et al. (1997b) describe two modifications to CATS that made this analysis possible: 1) its operator function model of pilot usage of cockpit automation was changed to represent the activities performed in a Boeing 747-400 cockpit during the Precision Descent, and 2) its representation of aircraft state data was modified to include simulator variables relevant to Precision Descent performance. A custom output report was also implemented to provide answers to the questions listed above (Figure 15). This CATS output was supplemented by further review of the simulator data files.

Process measures were obtained for each crew for run #6. This scenario was of moderate difficulty, and included a Mach/IAS assigned descent speed, a speed change clearance issued during the descent, and a canceled speed restriction at TOMSN. Its

Precision Descent clearance was issued 20 miles from the ADP, giving pilots approximately three minutes to prepare for descent (Tables 1, 2). With the exception of the combined Mach/IAS assigned descent speed, run #6 represented a "normal" Precision Descent: energy excess was moderate, the standard descent clearance was used, and the run occurred later in the day after crews were practiced flying the procedure.

```
*****************************************************
 output from data file crew3_scenario1.dat
*****************************************************

1.  Did the crew use VNAV to begin descent?  YES
VNAV configuration activity summary:
 descent forecast winds entry NOT predicted & explained
 ctas crossing restr entry NOT predicted & explained
 ctas notification clearance at time 31624
  (60.2867 nm before the VNAV T/D)
  (0 nm before the ADP)
 ctas descent clearance at time 31767
  (40.606 nm before the VNAV T/D)
  (39.606 nm before the ADP)
 descent speed entered at time 31851.7
  (28.9103 nm before the VNAV T/D)
  (27.9103 nm before the ADP)
 began descent at time 32083.2
  (1.99999 nm before the VNAV T/D)
  (-4.00001 nm before the ADP)

2.  Did the crew use VNAV to fly the descent?  YES
  (The descent speed entry was predicted & explained)

3.  Where did the crew begin the descent?
    Between the ADP and the VNAV T/D

4.  Did the crew use ALT hold to prevent early descent?N/A

5.  Did the crew use a mode besides VNAV in descent? NO
```

Figure 15. CATS output example (Callantine et al. 1997b).

Results

Results from the process analysis are presented in Table 6, along with a list of each crew's compliance errors. Crews 1, 3, 5 and 7 were in the "Chart with Bulletin" group; crews 2, 4, 6 and 8 were in the "Chart Only" group. The table lists the autopilot pitch mode selected by each crew to initiate descent, along with the crossing-restriction, descent speed, and cruise speed values that were entered into the CDU. Correct values for the crossing restriction and descent speed entries are listed in the column header; all cruise speed entries were in error. Table 6 also shows whether the flight crew entered the descent forecast winds correctly, and whether they used Altitude Hold to protect against an early VNAV descent.

Table 6

Descent Preparation Process Measures and Compliance Errors for all crews, Run #6

crew	Desc. mode Selected	Crossing restr. Entry (/190)	Desc. winds Entered	Desc. speed Entry (.84/340)	Cruise speed Entry*	Alt. Hold Used?	Compliance Erors
"Chart with Bulletin" crews							
1	VNAV	/190	yes	.84/340	-	no	-
3	FLCH	280/190	yes	340	-	yes	-
5	FLCH	/190	yes	.84/340	-	yes	cruise speed
7	VNAV	/190	no	.84/340	-	yes	TOMSN altitude
"Chart only" crews							
2	VNAV	/190	yes	340	.84	no	cruise speed
4	FLCH	/190	no	not entered	.84	yes	cruise speed, descent speed
6	VNAV	/190	yes	340	.84	no	cruise speed, ADP tolerance
8	VNAV	/190	(averaged)	not entered	-	no	TOMSN altitude

*incorrect action.

Task method observations. No between-group differences were observed in the mode selected to initiate descent, or in the CDU entry of the crossing restriction and the descent forecast winds. Note that the "Chart with Bulletin" crews did not always follow the Bulletin's recommendations; for example, two of the four used FLCH instead of the recommended VNAV mode to begin descent.

Between-group differences were observed in crew methods for entering the assigned descent speed in the CDU (a Mach/IAS combination), and in flight crew use of Altitude Hold. Three out of four "Chart with Bulletin" crews and none of the "Chart Only" crews entered the assigned descent speed correctly. Three of the "Chart Only" crews incorrectly entered the Mach value in the CDU's Cruise page. This error had two adverse consequences: 1) a cruise speed violation, and 2) an incorrect VNAV path: failure to correctly enter the assigned descent speed placed the VNAV T/D outside the 5-mile ADP tolerance.

Three out of four "Chart with Bulletin" crews and one "Chart Only" crew used Altitude Hold to prevent early descent. One of the "Chart Only" crews who did not use Altitude Hold began descent at the VNAV T/D, approximately eight miles from the ADP (three miles outside tolerance). This ADP error was caused by the combination of two performance errors: 1) incorrect descent speed entry in the CDU, and 2) no protection against an early VNAV descent.

Task timing and order. Figure 16 presents event timelines for each crew that show the order and timing of the two Precision Descent clearances, flight crew performance of three Descent Preparation tasks, and the beginning of descent.

Discussion of Process Analysis

This process analysis provided evidence that VNAV configuration methods used by the "Chart with Bulletin" group were influenced by the Bulletin's recommendations. It also showed evidence for compliance errors in the "Chart Only" group related to their deviations from these same recommendations. Four compliance errors observed in the "Chart Only" group (three cruise airspeed and one ADP tolerance error) were explained by incorrect performance of VNAV descent configuration tasks; if the tasks had been

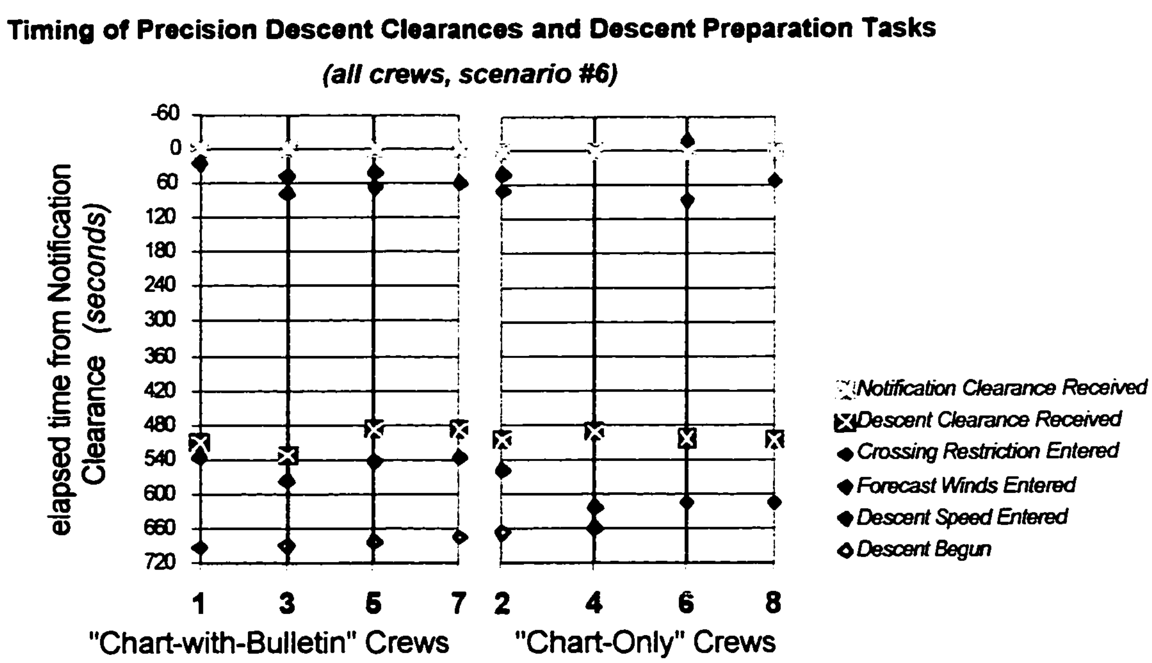


Figure 16. Timing of Precision Descent events and Descent Preparation tasks.

performed as described in the Bulletin, these errors would not have occurred.

Task timing and order. Figure 16 presents event timelines for each crew that show the order and timing of the two Precision Descent clearances, flight crew performance of three Descent Preparation tasks, and the beginning of descent.

Discussion of Process Analysis

This process analysis provided evidence that VNAV configuration methods used by the "Chart with Bulletin" group were influenced by the Bulletin's recommendations. It also showed evidence for compliance errors in the "Chart Only" group related to their deviations from these same recommendations. Four compliance errors observed in the "Chart Only" group (three cruise airspeed and one ADP tolerance error) were explained by incorrect performance of VNAV descent configuration tasks; if the tasks had been performed as described in the Bulletin, these errors would not have occurred.

Some possible benefits from more extensive process analyses. There was weaker evidence for Bulletin-related effects on task timing that suggested the Bulletin was effective in indicating external cues that crews could use to structure their task performance (Figure 16). A more complete analysis of the simulator data could substantiate the subtler effects of the Bulletin on task timing and task order that were suggested by the performance data presented in these timelines. Analysis of Descent Preparation process measures for other scenarios, or analysis of other measures from this scenario might strengthen the evidence for the presence of these task order and timing effects. This information could be of value to the Precision Descent and other procedure development efforts, guiding decisions about how and where to present information about procedure requirements and tasks. An expanded process analysis could also suggest how to modify the procedure to make it easier to understand and execute; for example, a more extensive analysis of crew descent initiation methods could help determine whether eliminating the 5 mile ADP tolerance would be appropriate.

CHAPTER 5:

Conclusions

PRECISION DESCENT PERFORMANCE AND TRAINING EVALUATION

Methods for Procedure Introduction

The training experiment presented in this thesis addressed three related questions:

1. Can document-based training alone result in adequate performance of the Precision Descent, or is formal training needed?
2. If document-based training is sufficient, which of the two methods compared in this study is better?
3. Is a cockpit procedure needed to insure correct performance of procedure tasks?

Adequacy of document-based training. After excluding scenario-related compliance errors, compliance with four of the six procedure compliance measures was 90% or better in the "Chart with Bulletin" condition, and compliance with the remaining two requirements -- 1) maintain cruise airspeed until reaching the assigned descent point, and 2) notify ATC if the VNAV T/D is out of range -- was better than 75% in the "Chart with Bulletin" condition. Based on our evaluation of procedure documents and observed crew task performance, it seems likely that improvements to procedure documentation coupled with minor changes to the procedure will further improve compliance, and that formal training will not be needed for its introduction.

Superiority of "Chart with Bulletin" condition. Before conducting this experiment it was unclear which condition would result in better compliance and add less to pilot workload. We believed that the Bulletin might reduce variability in method selection and make descent planning easier for the first descent; however, we felt that crews might not use the Bulletin, that the task of reading it might actually add to workload, that its value would diminish as crews gained experience with the Precision Descent, and that it was unnecessary -- because pilots were already familiar with the technique suggestions that it offered.

Instead we found consistent evidence that the Bulletin improved procedure compliance and made flight crew performance of the procedure easier. Fewer errors were observed on all six procedure requirements, ATC communications were shorter and less frequent, and pilots rated the procedure more favorably in the "Chart with Bulletin" group.

Improvements in Precision Descent compliance appeared related to crew use of the Bulletin's technique recommendations. Evidence to support this claim includes process measures from one scenario that showed fewer compliance errors in the "Chart with Bulletin" group, and increased use of its recommended techniques. Further support was provided by our observation of specific procedure violations in the "Chart Only" group resulting from their use of techniques that deviate from these recommendations.

This process analysis also shows that "Chart with Bulletin" crews did not need to follow all of the Bulletin's recommendations for satisfactory compliance (i.e., they did not use the Bulletin as a recipe for descent tasks). Instead, crews appeared to be selective in their use of its recommendations, using this document in the way it was intended to be used: as a list of technique suggestions that could be selectively employed.

A cockpit procedure for the Precision Descent. Compliance with the procedure did not appear dependent on crew selection of a particular method; for example, crews complied successfully with the procedure's requirements using both FLCH and VNAV autoflight pitch modes. Compliance errors were observed in the "Chart Only" group when VNAV descent configuration tasks were performed incorrectly. The "Chart with Bulletin" group did not make these task performance errors and avoided the related compliance errors. This suggests that the Bulletin's technique recommendations are effective in reducing performance problems, and that there may be no need to use a cockpit procedure to constrain method selection and task performance.

Recommendations for Improving Procedure Compliance

Evidence from a limited process analysis suggests that technique recommendations in the Bulletin are noticed and selectively used by pilots, and that its practical information leads to better task performance. Most recommendations for improving procedure compliance focus on exploiting the Bulletin's apparent effectiveness. The last two recommendations suggest modifying the procedure itself based on observed crew performance in the simulator evaluation.

1. Fix problems with Bulletin task descriptions that were identified by the overlay anayses. These include improving the description of the cruise-to-descent speed transition and explaining the dependency relationships among VNAV configuration tasks.

2. Offer more technique recommendations in the Bulletin. Brief task descriptions seem to work fine, although the content analysis shows the need to be careful of the exact wording used in the text. There was no evidence that the Bulletin contained too much information; the whole page appears to have been read and used by flight crews. Possible additions to the Bulletin include: explicit mention of Mach/IAS descent speed entries in the CDU, and description of a method for performing the top-of-descent speed transition.

3. Encourage flight crew usage of the Bulletin. Cross-reference the Bulletin in the Precision Descent Chart in order to increase crew awareness of the Bulletin, and encourage its use during normal operations. Flight crews in the experiment probably used the Bulletin more frequently than they would have in a normal flight setting because it was readily available.

4. Improve the description of the cruise speed requirement. Improve the Chart's presentation of this requirement by describing it in the "Precision Descent Procedure" text block.

5. Consider eliminating the 5 mile ADP tolerance. A limited analysis of process data from scenario #6 suggests that even when using VNAV to initiate descent, flight crews will begin descent at the ADP rather than the VNAV T/D. Eliminating the 5 mile tolerance on the ADP would simplify the procedure, and this evidence suggests that it might not discourage crews from using VNAV descent mode.

6. Alternatively, retain the 5 mile tolerance, but make it less prominent in procedure documentation. Instead of eliminating the tolerance on the ADP, its presentation in the two procedure documents could be softened. This should reduce the likelihood that crews would perceive it as a required procedure task, but still allow them some flexibility in determining their descent location.

7. Drop the requirement to "Notify ATC" if the VNAV T/D and the ADP are more than 5 miles apart. The requirement was intended to provide a safeguard against T/D and ADP calculation or communication errors; however, this reason was not made clear in the procedure documents. Even if the reason for this requirement were explained, flight crew compliance might be erratic, particularly since there is no way to detect non-compliance. During the simulator evaluation, flight crews in the "Chart Only" condition began descent within the charted 5 mile ADP tolerance when the VNAV T/D was out of range, and rarely contacted ATC. Crews in both conditions often used Flight Level Change or Vertical Speed to begin descent, a method choice which would make it unlikely that they would feel it necessary to contact ATC about the location of the VNAV T/D. It would probably be better to replace this requirement with instructions for crews to contact ATC if they are unable to comply with the assigned Precision Descent Clearance.

VALUE OF A MODEL-BASED APPROACH TO PROCEDURE DEVELOPMENT

This thesis demonstrated the value of a model-based approach for procedure and performance evaluation. Model-based descriptions of the relationship between the procedure, document content, and procedure tasks provided a framework for analyzing crew performance in two different training conditions. These systematic descriptions of the procedure task requirements and support documents were also used to critique the procedure's task structure and the adequacy of document coverage of its compliance requirements.

This method improved our understanding of differences in procedure compliance that were observed in the two experimental conditions. Our deeper understanding -- about the adequacy of procedure documentation, its influence on task performance, and the relationship between procedure requirements, task structure and observed task performance -- has supported our conclusions about the effectiveness of the two methods for procedure introduction and helped us to identify specific changes that could improve the procedure and lead to better compliance. These model-based analyses have thus improved the efficiency of procedure development by allowing us to make more effective use of the simulator performance data.

FUTURE WORK: OTHER POSSIBLE USES FOR MODEL-BASED APPROACH

A project is underway to develop a datalink method for air-ground negotiation of flight plan changes. This project will include development and simulator testing of new cockpit and controller displays and interfaces, and development of new pilot and controller procedures. There will be a number of opportunities during this project to investigate use of model-based analytic methods for design and evaluation of procedure, display, and interface prototypes. A few of these possibities are described briefly below.

Explore value of model-based analyses at an earlier stage in procedure design. This thesis described use of a task model as a framework for analyses of the Precision Descent procedure's task structure and its support documentation. These analyses were used to diagnose observed performance errors, and had the advantage of performance data that indicated where problems might be found. A logical next step would be to use these analyses for procedure and document design, and determine their value as a design tool in the absence of performance data.

Use model-based analytic methods for evaluating other kinds of prototyes. The systematic, model-based analysis of the relationship between task requirements, task context, and task performance presented in this thesis can also provide a framework for improving information obtained from simulator studies that don't address procedure training or development. These include evaluation of flight deck displays that change the format or content of information presented to pilots, interface modifications that alter flight crew interactions with cockpit automation, and communication media changes, such as the replacement of voice with datalink for pilot-controller communication. In each of these examples, model-based analyses could identify how changes in task context could affect operator activity, improve predictions about their impact on task performance and support a more complete analysis of observed performance.

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Appendices

APPENDIX A.
Pilot Questionnaire and Results

APPENDIX B.
Task Model

APPENDIX C.
Content Analysis of Documents

APPENDIX D.
Task Model Annotated with Document Content

APPENDIX A

Results from Pilot Questionnaire (non-narrative questions only)

QUESTION	***Chart with Bulletin***[i]		***Chart Only***	
Notification 1 "Company 123, expect PRECISION DESCENT."				
2. Did these actions change as you became more familiar with the PRECISION DESCENT?	yes: 6	no: 2	yes: 3	no: 5
Notification 2 "Company 123, expect PRECISION DESCENT, except disregard speed restriction at TOMSN."				
3. Was any portion of this notification unclear or possibly confusing?	yes: 0	no: 8	yes: 3	no: 5
PRECISION DESCENT Clearance "Company 123, Cleared for PRECISION DESCENT __ miles W of __,__ mach /__ kts."				
4. Was any portion of the above clearance unclear or possibly confusing?	yes: 3	no: 5	yes: 4	no: 4
PRECISION DESCENT Clearance 2 "Company 123, Cleared for PRECISION DESCENT ... Maintain FL___."				
4b. Was any portion of the above clearance unclear or possibly confusing?	yes: 2	no: 4	yes: 2	no: 6
6. Did these actions change as you became more familiar with the PRECISION DESCENT?	yes: 4	no: 4	yes: 4	no: 4
7. Did you usually have adequate time to respond to this clearance?	yes: 7	no: 1	yes: 7	no: 1
8. Did you always have adequate time to respond to this clearance?	yes: 3	no: 4	yes: 5	no: 3
13. Did you contact ATC?	yes: 5	no: 2	yes: 5.5	no: 2.5
"Descent Speed Change Clearance": "Company 123, reduce (increase) speed to xxx knots, continue Precision Descent."				
16. Was any portion of this clearance unclear or possibly confusing?	yes: 0	no: 8	yes: 5	no: 3
17. Were any callbacks to ATC necessary to clarify any of the clearances listed above?	yes: 5	no: 3	yes: 8	no: 0
22. How acceptable was the PRECISION DESCENT Clearance phraseology?	1.75[ii]		1.25	
23. How acceptable was the phraseology used in the other clearances issued during the PRECISION DESCENT?	1.25		1.125	
24. How acceptable was the assigned descent speed?	0.625		0	
25. How acceptable was the assigned descent point?	1.87		1.87	
26. Overall, how acceptable was the PRECISION DESCENT?	1.5		0.5	
27. Did you feel rushed due to any part of the PRECISION DESCENT?	yes: 7	no: 1	yes: 7	no: 1
29. Did the PRECISION DESCENT plate prepare you sufficiently for the PRECISION DESCENT?	yes: 7	no: 1	yes: 4	no: 4
31. Did (would) you use techniques suggested in the "NASA Flight Manual Bulletin"?	yes: 5	no: 3	yes: 5	no: 1
32. Should either the PRECISION DESCENT page or the Flight Manual Bulletin have contained less, or less detailed info.?	yes: 0	no: 8	yes: 2	no: 5
33. Do you think simulator training is needed for introduction of the PRECISION DESCENT?	yes: 2	no: 6	yes: 6	no: 2
33b. Do you think the FLIGHT MANUAL BULLETIN is needed for introduction of the PRECISION DESCENT?	yes: 5	no: 1	yes: 5	no: 1
34. How many descents did it take for the PRECISION DESCENT to become comfortable, or routine?	3.25		2.8125	

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[i] n = 8 pilots per training condition.

[ii] Average Likert scores (from -3: "completely unacceptable" to +3: "completely acceptable")

PRECISION DESCENT Evaluation -- June 1996

Pilot Questionnaire

BACKGROUND INFORMATION

Date: ________________ Position: ________________ Hours flying 747-400: ________________

CLEARANCES AND COMPLIANCE METHODS

Notification 1
"Company 123, expect PRECISION DESCENT."

1. When you received this ATC notification what did you typically do? (Describe your actions, including any MCP and/or CDU inputs).

2. Did these actions change as you became more familiar with the PRECISION DESCENT? Yes _____ No _____ (If yes, explain)

Notification 2
"Company 123, expect PRECISION DESCENT, except disregard speed restriction at TOMSN."

3. Was any portion of this notification unclear or possibly confusing? Yes _____ No _____

PRECISION DESCENT Clearance
"Company 123, Cleared for PRECISION DESCENT ____ miles West of ____, ____ mach /____ knots."

4. Was any portion of the above clearance unclear or possibly confusing? Yes _____ No _____ (If yes, please circle and explain)

PRECISION DESCENT Clearance 2
"Company 123, Cleared for PRECISION DESCENT ____ miles West of ____, ____ mach /____ knots. Maintain FL____."

4b. Was any portion of the above clearance unclear or possibly confusing? Yes _____ No _____ (If yes, please circle and explain)

5. When you received the PRECISION DESCENT clearance what did you typically do? (Describe your actions)

6. Did these actions change as you became more familiar with the PRECISION DESCENT? Yes _____ No _____ (If yes, explain)

7. Did you usually have adequate time to respond to this clearance? Yes _____ No _____ (If no, explain)

8. Did you <u>always</u> have adequate time to respond to this clearance? Yes _____ No _____ (If no, explain)

9. Which methods did you use to locate the assigned descent point? (check all that apply)
   _____ Monitor PROG page
   _____ Distance-to-go to a pre-existing waypoint on the FMS route (e.g., TOMSN)
   _____ Distance-to-go to a pilot-defined waypoint (e.g., TOMSN01)
   _____ Circle from a fix
   _____ Other (please describe)_____________________________________

10. Which method(s) did you feel worked best for you? Why?

11. What was the allowed tolerance on the assigned descent point when flying VNAV descents?
    +/- ______ miles

12. What did you do when your VNAV T/D was outside this tolerance?

13. Did you contact ATC? Why (or why not)?

"Intermediate Altitude Clearance":
"Company 123, maintain FLxxx for traffic. Expect Precision Descent."

14. When you received this clearance what did you typically do?
    (Describe your actions)

"Descent Speed Change Clearance":
"Company 123, reduce(increase) speed to xxx knots, continue Precision Descent."

15. When you received this clearance what did you typically do?
    (Describe your actions)

16. Was any portion of this clearance unclear or possibly confusing?

17. Were any callbacks to ATC necessary to clarify any of the clearances listed above?
    Yes _____ No _____ (If yes, please explain)

18. What was the charted tolerance on the assigned descent speed? +/- _______knots.

19. Describe what prompted any thrust corrections you used in descent.
    (e.g. speed near or outside tolerance, FMS thrust requests, crossing restriction, other...)

20. Describe what prompted any drag corrections you used in descent.
    (e.g. speed near or outside tolerance, FMS drag requests, crossing restriction, other...)

21. Did you enter winds in the Descent Forecast page? Yes _____ No _____

PROCEDURE ACCEPTABILITY

Indicate on the scales your responses to the following questions.

22. How acceptable was the PRECISION DESCENT Clearance phraseology?

Completely Unacceptable — Completely Acceptable

23. How acceptable was the phraseology used in the other clearances issued during the PRECISION DESCENT?

Completely Unacceptable — Completely Acceptable

24. How acceptable was the assigned descent speed?

Completely Unacceptable — Completely

25. How acceptable was the assigned descent point?

Completely Unacceptable — Completely Acceptable

26. Overall, how acceptable was the PRECISION DESCENT?

Completely Unacceptable — Completely Acceptable

Acceptable

27. Did you feel rushed due to any part of the PRECISION DESCENT? Yes ____ No ____
(If yes, please describe)

28. Under what (other) conditions might you decline a PRECISION DESCENT Clearance? (e.g., turbulence, high workload...)

ADEQUACY OF BRIEFING MATERIAL

29. Did the PRECISION DESCENT plate prepare you sufficiently for the PRECISION DESCENT?
Yes ____ No ____

30. Did (would) the "NASA Flight Manual Bulletin" help clarify the procedure?

____ Yes, completely.
____ Somewhat, but not enough.
____ Not at all.

31. Did (would) you use techniques suggested in the "NASA Flight Manual Bulletin"?
Yes ____ No ____ (please elaborate)

32. Should either the PRECISION DESCENT page or the Flight Manual Bulletin have contained less information, or less detailed information?

33. Do you think simulator training is needed for introduction of the PRECISION DESCENT?
Yes ____ No ____ (If so, why?)

33b. Do you think the FLIGHT MANUAL BULLETIN is needed for introduction of the PRECISION DESCENT?

Yes _____ No _____ (if so, why?)

OTHER

34. How many descents did it take for the PRECISION DESCENT to become comfortable, or routine?

35. Describe any techniques you may have developed for flying the PRECISION DESCENT.

36. How could the PRECISION DESCENT be improved?

APPENDIX B

Precision Descent Task Model

Task Activities:	*Condition*	*Data needed; source & destination*	*Timing: after*	*Timing: until*
I. Prepare for descent	notified to "expect Precision Descent"		Precision Descent Notification	
A. Configure VNAV				
1. enter descent forecast winds	data available	descent winds, altitudes source: ACARS dest.: DES Fcst. Page		
2. enter crossing restriction (at meter fix)	metering waypoint known	metering wpt. crossing restrictions source: Chart dest: LEGS page		
3. enter descent speed in FMS	data available	Ass. Descent [Mach/]spd source: Dscnt. Clr. dest: DES page	Precision Descent Clearance?	
B. Configure MCP/Enable Descent	cleared for descent			
1. enter altitude		metering waypt. xr-alt source: Chart dest: MCP alt window		
2. use ALT HOLD to prevent early descent	mismatch between MCP altitude and cleared altitude (and/or) not cleared to descend at VNAV T/D			
3. push alt. knob	MCP dialed to cleared alt. (and) in VNAV mode (and) past T/D when cleared to descend			
C. Determine where to descend	data available	Assigned Descent Point source: Dscnt. Clr.	Precision Descent Clearance	
1. configure ADP	time available	Assigned Descent Point source: Dscnt. Clr.		
a) Method 1: configure ADP as user-defined wpt		dest: LEGS page		
b) Method 2: configure ADP fix circle		dest: FIX page		
2. determine a/c position relative to ADP		Assigned Descent Point source: Dscnt. Clr.		
a) Method 1: monitor ADP on PROG page				
b) Method 2: monitor ADP on Nav Display	ADP fix circle programmed (or) ADP waypoint programmed			
3. determine if T/D is within 5nm of ADP	VNAV programmed for Precision Descent	Assigned Descent Point, Assigned Descent Speed source: Dscnt. Clr. ADP window source: Chart		

a) Method 1: use PROG page information				
b) Method 2: use Nav Display	fix circles programmed			
4. choose descent location	T/D is within 5nm of ADP			
D. Monitor planned descent point relative to a/c position	Descent point determined	point within ADP window source: Dscnt. Clr. source: Chart		
1. Method 1: monitor PROG page				
2. Method 2: monitor CRZ page				
3. Method 3: monitor Nav Display				
E. contact ATC	T/D is more than 5nm from ADP			
1. contact ATC				
2. inform "T/D out of range"				
F. avoid late descent	Descent Clearance *not* received		Precision Descent Notif.	
1. monitor approach to descent				
a) Method 1: monitor T/D on PROG page				
b) Method 2: monitor T/D on CRZ page				
c) Method 3: monitor T/D on Nav Display				
d) Method 4: monitor FMS messages				
2. request descent clearance	close to T/D			within ADP window
II. Transition to Descent Speed	cleared for descent current speed != ADS	Ass. Descent [Mach/] Spd source: Dscnt. Clr.	within ADP window or at ADP	
A. Method 1: Use MCP to achieve speed target	current speed >= ADS	Assigned Descent Speed source: Dscnt. Clr.		
1. open MCP speed window	speed window blank			
2. select MCP speed	mach selected			
3. adjust MCP speed window	MCP speed window != ADS			current IAS = ADS
B. Method 2: Use MCP to achieve mach target	Assigned Descent Mach (ADM) provided (or) current speed < ADS	Assigned Descent Mach source: Dscnt. Clr. (or) Cruise Mach		
1. open MCP Mach/IAS window	Mach/IASwindow blank			
2. select MCP mach	speed selected			
3. adjust MCP Mach window	MCP mach window != ADM			*current mach = ADM*
C. Method 3: Use VNAV to achieve (mach/)speed target	T/D is within ADP window	Ass. Descent [Mach/] Spd source: Dscnt. Clr.		
1. enter DES (mach/)speed	Assigned Descent (Mach) Speed not programmed	Ass. Descent [Mach/] Spd source: Dscnt. Clr.		
2. engage VNAV	VNAV not engaged			
D. Method 4: Adjust V/S to achieve speed target	descent mode = V/S Mach/IAS <> assigned value	Ass. Descent Mach (or) Assigned Descent Speed source: Dscnt. Clr.		

1. increase descent rate	current mach < ADM (or) current speed < ADS			
2. decrease descent rate	current speed > ADS			current speed = ADS
III. Begin Descent	cleared for descent (a/c is within ADP window) and current speed >= ADS	ADP window location source: Descent Clr., Chart		
B. Enable descent (duplicates "config MCP")	descent not enabled			
1. set MCP alt. to cleared altitude	MCP alt window <> cleared altitude	metering wpt. xr-alt source: Chart		
2. push alt. knob	current mode is ALT HOLD? *(check)*			
C. start descent				
1. Method 1: V/S mode	desc. before VNAV T/D (or) VNAV not programmed (or) above/below VNAV path (or) need to control speed			
a) push V/S button	V/S not engaged			
b) enter vertical speed	V/S win. != desired V/S	'desired' vertical speed		
2. Method 2: FLCH mode	desc. before VNAV T/D (or) VNAV not programmed (or) need to control speed			
a) push FLCH button	FLCH not engaged			
3. Method 3: VNAV mode	T/D within ADP Window VNAV profile acceptable			
a) push VNAV button	VNAV not engaged?			
b) line select Descend Direct	planned descent point before VNAV T/D			
D. Inform ATC				
1. contact ATC				
2. announce "leaving altitude"				past ADP window
IV. Maintain Descent Speed within tolerance	in descent	Assigned Descent Speed source: Dscnt. Clr., tolerance	current speed = ADS	
A. Method 1: adjust thrust or drag to achieve speed target	VNAV mode engaged (or) energy excess/deficit (and) current speed outside tolerance (or) current speed <>l ADS			
1. increase throttles	speed error is small (or) current speed < ADS (and) speed brakes retracted (and) energy deficit			
2. decrease throttles	current speed < ADS (and) throttles not at idle posn. (and) energy excess			

3. increase speed brakes	current speed < ADS (and) speed brakes retracted (and) speed error is small (or) adjustment is short term? (and) energy excess			
4. decrease speed brakes	current speed < ADS (and) throttles are not at idle (and) energy deficit			
B. Method 2: Speed intervene to achieve speed target	in VNAV mode (and) speed error in VNAV approaches tolerance (or) VNAV speed <> ADS			
1. push speed knob	speed window blank			
2. adjust MCP speed	MCP IAS window <> ADS			
C. Method 3: Use FLCH to achieve speed target	VNAV not programmed (or) speed error in VNAV approaches tolerance (or) ADS changed			
1. push FLCH button	not in FLCH mode			
2. adjust MCP speed	MCP IAS window <> ADS			
D. Method 4: Use VNAV to maintain speed target	VNAV speed and profile acceptable			
1. engage VNAV	VNAV mode not active			
2. close MCP speed window	MCP speed window open (not blank)			
E. Prepare VNAV to maintain speed target	VNAV setup not current			
1. enter DES speed	VNAV speed <> ADS			
2. enter metering waypoint crossing restriction	entered wpt-xr <> cleared wpt-xr	metering wpt. crossing restriction source: Chart		capture xr-alt; (or) decel distance
V. Prepare to meet crossing restr's		metering wpt. crossing restriction source: Chart	capture xr-alt; (or) decel distance	
A. Monitor vertical path error				
B. Monitor distance to metering waypoint		metering wpt. source: Chart		
C. estimate distance needed to decelerate		metering wpt., crossing airspeed source: Chart		
D. monitor/adjust speed as needed				
1. monitor airspeed				
2. determine energy excess/deficit				
3. adjust throttles				
4. adjust speed brakes				
5. adjust MCP speed				
D. monitor/adjust descent rate as needed.				
1. monitor altitude				
2. adjust vertical speed...				metering waypoint

APPENDIX C

Content Analysis of Precision Descent Documents

PART 1: SUMMARY STATISTICS FROM CONTENT ANALYSIS

Bulletin Content

90 listed 'idea units'

67 <u>ATC Procedure Information Category</u>

3 procedure applicability
8 what to expect
6 CTAS concept
19 document content
7 compliance target location
24 compliance target interpretation
0 compliance target value

85 <u>Procedure Compliance Measure</u>

11 notify ATC
8 cruise airspeed
16 descent location
19 descent speed
15 speed transition
8 crossing speed
8 crossing altitude

80 <u>Task Information Category</u>

20 method description
30 info...
  20 info identity
  6 info source
  3 info destination
10 task timing
10 task condition
10 purpose

Chart Content

84 listed 'idea units'

80 <u>ATC Procedure Information Category</u>

10 procedure applicability
26 what to expect
3 CTAS concept
8 document content
8 compliance target location
21 compliance target interpretation
4 compliance target value

58 <u>Procedure Compliance Measure</u>

2 notify ATC
5 cruise airspeed
10 descent location
10 descent speed
3 speed transition
15 crossing speed
13 crossing altitude

37 <u>Task Information Category</u>

4 method description
19 info...
  13 info identity
  6 info source
  0 info destination
11 task timing
3 task condition
0 purpose

PART 2: LIST OF 'IDEA UNITS' FROM PRECISION DESCENT CHART

C1. (Procedure title is) "Precision Descent."

C2. (Procedure is for) "Denver, Colorado."

C3. (Procedure is for) "Denver International Airport."

C4. (Procedure associated with) "TOMSN/RAMMS1 Arrival"

C5. (Procedure associated with TOMSN/RAMMS1 Arrival Chart.)

C6. Chart is printed by "NASA."

C7. (Procedure description is) "For TURBO JET Aircraft Only."

C8. (Procedure passes) "(via TOMSN or RAMMS)" (arrival gate.)

C9. (Arrival gate is variable.)

C10. (These are the) "PRECISION DESCENT CLEARANCES."

C11. (There are two Precision Descent Clearances.) *(implied by section content)*

C12. (Precision Descent Notification will be given by controller.) *(implied)*

C13. "PRECISION DESCENT Notification:" [phraseology is] *"Company 123, expect PRECISION DESCENT."*

C14. "PRECISION DESCENT Clearance:" [phraseology is] ... *"Company 123, cleared for the PRECISION DESCENT at __nm E/W of __(fix), __knots."*

C15. (PRECISION DESCENT CLearance will be) "... (Issued approximately 2 minutes before the assigned descent point)..."

C16. (The Precision Descent Clearance has a standard format.)

C17. (Fix distance value in clearance is variable) " ... __nm..."

C18. (Direction from fix in clearance is variable) "... E/W ..."

C19. (Reference fix used in clearance is variable) "... ___ (fix), ..."

C20. (Speed value contained in clearance is variable) "... __knots)."

C21. (The following describes the) "PRECISION DESCENT PROCEDURE [for] Denver International Airport."

C22. "To use the PRECISION DESCENT procedure, ... controller will provide the following in the PRECISION DESCENT Clearance." (Precision Descent Clearance is needed to use the Precision Descent procedure.)

C23. "... the Denver Center controller..."

C24. (Clearance includes) "• An **assigned descent point**..."

C25. "...given as a distance from a navaid."

C26. "(If VNAV T/D is within +/-5nm of **assigned descent point**..."

C27. "...aircraft may descend using VNAV.)" *(parenthetic)*

C28. (Clearance includes) "• A **descent speed**..."

C29. "...to be maintained within +/-10 knots..."

C30. "...in the descent."

C31. "Refer to this plate for:

• speed and altitude **crossing restrictions**..."

C32. "...at TOMSN and RAMMS."

C33. "For **lateral routing** refer to the TOMSN/RAMMS1 Arrival Plate."

C34. (Diagram is a) "VERTICAL AND SPEED PROFILE."

Possible correct interpretation of image elements:

C35. Gray bar/boxes represent speed targets zones.

C36. Black line represents abstraction of altitude profile.

C37. Black line represents abstraction of lateral route.

C38. Circle on black line represents assigned descent point.

C39. Star on black line represents metering waypoint.

C40. Vertical dimension represents altitude.

C41. Horizontal dimension represents time.

C42. Horizontal dimension also represents along-track distance.

C43. Dashed lines link speed zones to altitude targets and lateral route positions

If the images have the symbolic meaning listed above, then the following might be inferred:

C44. Maintain Cruise Mach...*(implied meaning of gray block with arrow, etc.)*

C45. ... until reaching the assigned descent point. *(implied meaning of labeled gray block with arrow, etc.)*

C46. Change speed after assigned descent point. *(implied by dashed line from block boundaries to [ADP] symbol on black [profile] line)*

C47. Once reached, maintain Descent Speed until necessary to slow for crossing speed. *(implied: labeled gray block, dashed line to profile line)*

C48. Decelerate for crossing speed until reaching crossing waypoint. *(implied: labeled gray block, dashed line to profile and [bottom of descent] symbol)*

C49. Maintain level flight until assigned descent point. *(implied: profile line is flat to left of circle [ADP symbol] ..).*

C50. Begin descent at assigned descent point." *(implied: profile line slopes to right of circle..)*

C51. Maintain constant descent rate until shallowing for crossing restriction." *(implied: profile line is straight in segment between dashed lines..)*

C52. Pass through bottom of descent waypoint while in descent.* *(implied: profile line slanted downward [BOD] symbol)*

NOTE: these are plausible inferences based on the graphic, but not part of the procedure.

C53. "Maintain cruise altitude and airspeed until reaching assigned descent point." *(reinforced by placement on graphic)*

C54. "Maintain descent speed within +/- 10 knots until slowing for crossing restriction." *(reinforced by arrow and placement on graphic)*

C55. "Initiate descent and speed changes at assigned descent point."

C56. "If VNAV T/D is within +/- 5nm of this point, ..."

C57. "... aircraft may descend using VNAV."

C58. Preceding note refers to assigned descent point. *(implied by arrow from note to [ADP] symbol)*

C59. "Expect radar vectors." ...

C60. ... (after passing metering waypoint.) *(location of note)*

C61. Speed and altitude are not defined after metering waypoint. *(implicit: no gray boxes; no profile line past [wpt] symbol)*

C62. Procedure ends at metering waypoint. *(implicit: no gray boxes; no profile line past [wpt] symbol)*

C63. "FMS NOTE": (special note for those using FMS).

C64. "If the VNAV T/D occurs more than 5nm from the assigned descent point ..."

C65. "...contact ATC."

C66. Crossing restrictions at bottom of descent. *(text boxes with arrows, attached to bottom-of-descent symbol)*

C67. Two different bottom of descent possibilities. *(two boxes)*

C68. (One bottom of descent waypoints is) "TOMSN."

C69. "Cross [TOMSN] at FL190..."

C70. "...and 250 knots."

C71. (A second bottom of descent waypoints is) "RAMMS."

C72. "Cross [RAMMS] at 17000'..."

C73. "...and 250 knots."

C74. (The following are) "**IMPORTANT NOTES**".

C75. "**• Mid-descent speed changes** [might be] **given by ATC...**" (during Precision Descent.)

C76. "**...speed changes...do not cancel PRECISION DESCENT crossing restrictions.**"

C77. "Intermediate descent altitudes are not incorporated in this procedure."

C78. "ATC requests to maintain intermediate altitude may be made..."

C79. "...due to traffic."

C80. "Expect to resume PRECISION DESCENT upon clearing traffic."

C81. "Updated descent wind data..."

C82. "...may be provided..."

C83. "...by ATC..."

C84. "...for FMS entry."

PART 3: LIST OF "IDEA UNITS" FROM NASA FLIGHT MANUAL BULLETIN

B1. (Document is a) "Flight Manual Bulletin."
B2. (Document has a) "NASA" (logo.)
B3. (Document is published by NASA.)
B4. (Document dated) "June 1996."
B5. (Document is current.)
B6. (Document format resembles United Airlines Flight Manual Bulletins.)
B7. (About:) "Precision Descent Clearance..."
B8. (About:) "Precision Descent... Technique."
B9. "Precision Descent Clearance is currently being evaluated..."
B10. "...at Denver..."
B11. "...ARTCC."
B12. "Descent clearance information [is] used in [a] procedure..."
B13. "Descent c learance information is generated by a ...computer system..."
B14. an "*air traffic control* computer system..."
B15. "a *new* air traffic control computer system..."
B16. "...is intended to be compatible with VNAV."
B17. "The suggested technique below..."
B18. "...demonstrates how..."
B19. "...VNAV can be used to comply with the Precision Descent.
B20. "Notification to expect the Precision Descent Clearance..."
B21. "... will be received..." *(count on being notified)*
B22. "...approximately 10 minutes before descent."
B23. (After Notification, ...)
B24. "• Prepare to comply..."
B25. "...by entering crossing restriction ..."
B26. "...from PRECISION DESCENT PLATE..."
B27. "....in CDU LEGS page."
B28. "Descent forecast winds..."
B29. "... may be provided..."
B30. "...by ATC."
B31. "If forecast winds are provided:" ...
B32. ..."• enter in DES Forecast page."
B33. "PRECISION DESCENT Clearance" (Phraseology example)
B34. "United 123, cleared for PRECISION DESCENT, 20nm West of FROGS, 300kts."
B35. ""assigned descent point: ..." (ADP)
B36. (is included in PRECISION DESCENT Clearance.)
B37. "...actual values will vary" (from 20nm West of FROGS.)
B38. """assigned descent speed: ..."
B39. "(ADS) (is included in PRECISION DESCENT Clearance.)
B40. "...actual values will vary" (from 300kts.)
B41. (About) "Descent Point".
B42. "The aircraft may descend using VNAV ..."
B43. "...if the VNAV T/D is within [tolerance] of the assigned descent point".
B44. (ADP tolerance is) "...5nm..."
B45. "To compare the VNAV T/D to the assigned descent point:" (do the following.)

MISSING INFORMATION/STATEMENT: "and to prepare for VNAV descent" (second reason for following; notmentioned.)

B46. "Enter the assigned descent speed..."
B47. "...in the DES page..."
B48. "...then ..."
B49. "...recompute the VNAV T/D."
B50. (after recomputing the T/D)
B51. "Refer to the PROG page..."
B52. "...to determine difference..."
B53. "...between the new T/D and the assigned descent point."
B54. (Use the) "...new T/D..." (in the comparison.)
B55. "See EXAMPLE" (for method.)
B56. (Use PROG page to monitor a/c position relative to the T/D.) *(implicit)*
B57. (Use PROG page to monitor a/c position relative to the ADP.) *(implicit)*
B58. from example: T/D-ADP-difference = ADP-distance-from-FROGS - (a/c-distance-to-FROGS minus a/c-distance-to-T/D)
B59. "If the VNAV T/D is within 5nm of the assigned descent point: ..."
B60. "...Plan to use VNAV to initiate and fly the descent."
B61. "If the VNAV T/D is *not* within 5nm of the [ADP]: ..."
B62. "...Inform ATC." (and...)
B63. "...Plan to recapture the VNAV path ..."
B64. "...after descent has been initiated." (and...)
B65. "... Consider using ALT HOLD ..."
B66. "...to prevent early descent..."
B67. "...while waiting for descent clearance."
B68. (About:) "CRUISE-TO-DESCENT SPEED TRANSITION"
B69. "...VNAV's descent initiation method is compatible ..."
B70. "...with the recommendations below."
B71. "If assigned descent speed is slower than cruise airspeed..."
B72. "...Begin deceleration ..."
B73. "...after reaching the assigned descent point."
B74. "If assigned descent speed is faster than cruise airspeed..."

MISSING STATEMENT: Begin acceleration after ADP. (Should have been here, but wasn't.)

B75. "...Maintain cruise mach..."
B76. "...or assigned mach [if provided]..."
B77. "...until assigned airspeed is reached."

B78. (Use assigned or cruise mach to accelerate to assigned airspeed.)

B79. (About:) "SPEED IN DESCENT"

B80. "...maintain assigned descent speed ..."

B81. "...within 10 knots."

B82. "Use thrust ..."

B83. "...as needed..." *(if energy is inadequate)*

B84. "...to maintain assigned descent speed..."

B85. "Use ...drag..."

B86. "...as needed..." *(if energy is excessive)*

B87. "...to maintain assigned descent speed..."

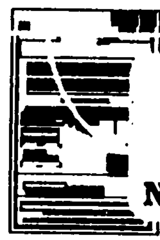
B88. (Document is a) "...Flight Manual Bulletin."

B89. (Document is a) "NASA Flight Manual Bulletin."

B90. "PAGE 1 of 1" (This page is the complete Bulletin.)

APPENDIX C

PART 4: ANALYSIS OF PRECISION DESCENT CHART

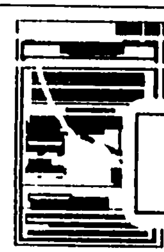


NASA

PRECISION DESCENT
DENVER, COLO
DENVER INTL
TOMSN/RAMMS 2 Arrival

Figure C1. Side 1 header information.

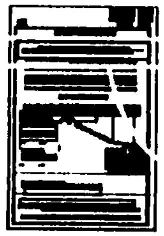
	Proposition	*Procedure Information Category*	*Procedure Compliance Measure*	*Cockpit Task Information Category*
C_1.	(Procedure title is) "Precision Descent."	procedure applicability document contents		
C_2.	(Procedure is for) "Denver, Colorado."	procedure applicability document contents		
C_3.	(Procedure is for) "Denver International Airport."	procedure applicability document contents		
C_4.	(Procedure associated with) "TOMSN/RAMMS 1 Arrival"	procedure applicability		
C_5.	(Procedure associated with TOMSN/RAMMS 1 Arrival Chart.)	compliance target source	crossing speed, crossing altitude	
C_6.	Chart is printed by "NASA."	CTAS concept		



For TURBO JET Aircraft Only
(via TOMSN or RAMMS)

Figure C2. Untitled top block.

C_7.	(Procedure description is) "For TURBO JET Aircraft Only."	procedure applicability		
C_8.	(Procedure passes) "(via TOMSN or RAMMS)" (arrival gate.)	what to expect document contents		
C_9.	(Arrival gate is variable.)	what to expect		



PRECISION DESCENT CLEARANCES

PRECISION DESCENT Notification: *"Company123, expect PRECISION DESCENT."*

PRECISION DESCENT Clearance: (issued approximately 2 minutes before the assigned descent point)

"Company123, cleared for the PRECISION DESCENT at ___nm E/W of ___ (fix), ___knots."

Figure C3. Clearance block.

C_10.	(These are the) "PRECISION DESCENT CLEARANCES."	what to expect		
C_11.	(There are two Precision Descent Clearances.) *(implied by section content)*	what to expect		
C_12.	(Precision Descent Notification will be given by controller.) *(implied)*	what to expect		
C_13.	"PRECISION DESCENT Notification:" [phraseology is] *"Company 123, expect PRECISION DESCENT."*	what to expect		
C_14.	"PRECISION DESCENT Clearance:" [phraseology is] ... *"Company 123, cleared for the PRECISION DESCENT at __nm E/W of __(fix), __knots."*	compliance target source	descent location, descent speed	
C_15.	(PRECISION DESCENT CLearance will be) "... (Issued approximately 2 minutes before the assigned descent point)..."	what to expect		
C_16.	(The Precision Descent Clearance has a standard format.)	what to expect		
C_17.	(Fix distance value in clearance is variable) " ... __nm..."	what to expect	descent location	
C_18.	(Direction from fix in clearance is variable) "... E/W ..."	what to expect	descent location	
C_19.	(Reference fix used in clearance is variable) "... ___ (fix), ..."	what to expect	descent location	
C_20.	(Speed value contained in clearance is variable) "... __knots)."	what to expect	descent speed	

PRECISION DESCENT PROCEDURE Denver International Airport

To use the PRECISION DESCENT procedure, the Denver Center controller will provide the following in the PRECISION DESCENT clearance:

• An **assigned descent point** given at a distance from a navaid. (If VNAV T/D is within +/- 5nm of **assigned descent point**, aircraft may descend using VNAV.)

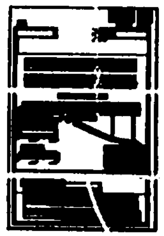
• A **descent speed** to be maintained within +/- 10 knots in the descent.

Refer to this plate for:
• Speed and altitude **crossing restriction** at TOMSN and RAMMS

For **Lateral routing** refer to the TOMSN/RAMMS 2 ARRIVAL plate.

Figure C4. Precision Descent Procedure description block.

C_21.	(The following describes the) "PRECISION DESCENT PROCEDURE [for] Denver International Airport."	what to expect document contents procedure applicability		
C_22.	"To use the PRECISION DESCENT procedure, ... controller will provide the following in the PRECISION DESCENT Clearance." (Precision Descent Clearance is needed to use the Precision Descent procedure.)	compliance target source, what to expect		
C_23.	"... the Denver Center controller..."	compliance target source		
C_24.	(Clearance includes) "• An **assigned descent point**...."	compliance target source	descent location	info identity info source
C_25.	"...given as a distance from a navaid."	compliance target usage	descent location	
C_26.	"(If VNAV T/D is within +/-5nm of **assigned descent point**..."	compliance target usage		condition
C_27.	"...aircraft may descend using VNAV.)" *(parenthetic)*			method
C_28.	(Clearance includes) "• A **descent speed**..."	compliance target source	descent speed	info identity info source
C_29.	"...to be maintained within +/-10 knots..."	compliance target usage	descent speed	
C_30.	"...in the descent."	compliance target usage	cruise airspeed, descent speed	timing
C_31.	"Refer to this plate for: • speed and altitude **crossing restrictions**..."	compliance target source	crossing speed, crossing altitude	info source
C_32.	"...at TOMSN and RAMMS."	what to expect procedure applicability		
C_33.	"For **lateral routing** refer to the TOMSN/RAMMS 1 Arrival Plate."	compliance target source		info source



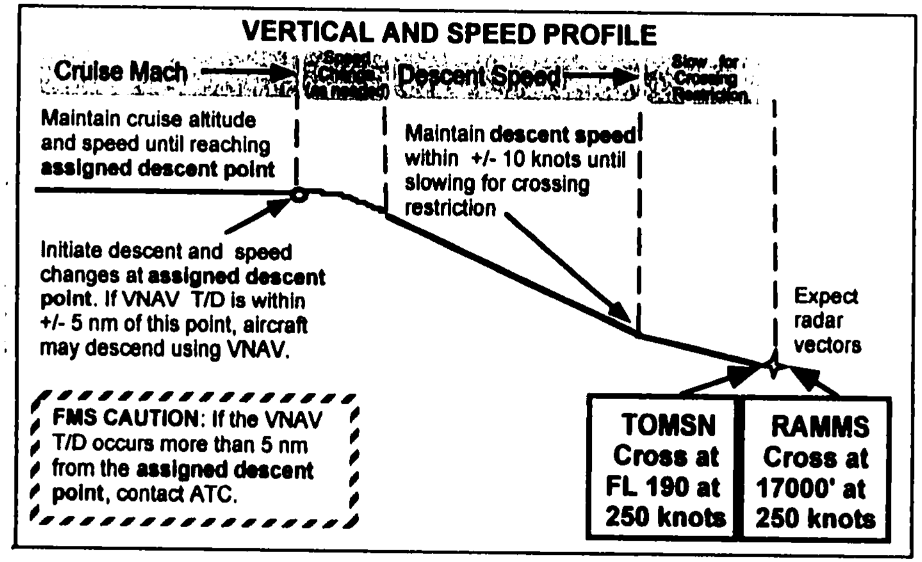


Figure C5. Profile graphic block.

The "Figure C5" description begins by trying to list what is symbolically represented in the graphic: temporal information (left to right), spatial information (vertical profile), specific locations implied by circle and star; meaning of connecting arrows, dashed lines, and placement of notes.

C_34. (Diagram is a) "VERTICAL AND SPEED PROFILE."	document content		

Possible correct Interpretation of Image elements: *document content?*

C_35. Gray bar/boxes represent speed targets zones.			
C_36. Black line represents abstraction of altitude profile.			
C_37. Black line represents abstraction of lateral route.			
C_38. Circle on black line represents assigned descent point.			
C_39. Star on black line represents metering waypoint.			
C_40. Vertical dimension represents altitude.			
C_41. Horizontal dimension represents time.			
C_42. Horizontal dimension also represents along-track distance.			
C_43. Dashed lines link speed zones to altitude targets and lateral route positions			

If the images have the symbolic meaning listed above, then the following might be inferred:

C_44.	Maintain Cruise Mach...*(implied meaning of gray block with arrow, etc.)*	compliance target usage	cruise airspeed	info identity
C_45.	... until reaching the assigned descent point. *(implied meaning of labeled gray block with arrow, etc.)*	compliance target usage	cruise airspeed	timing
C_46.	Change speed after assigned descent point. *(implied by dashed line from block boundaries to [ADP] symbol on black [profile] line)*	compliance target usage	descent speed, speed transition	timing info identity
C_47.	Once reached, maintain Descent Speed until necessary to slow for crossing speed. *(implied: labeled gray block, dashed line to profile line)*	compliance target usage	descent speed, crossing speed	info identity timing
C_48.	Decelerate for crossing speed until reaching crossing waypoint. *(implied: labeled gray block, dashed line to profile and [bottom of descent] symbol)*	compliance target usage	descent speed, crossing speed	info timing
C_49.	Maintain level flight until assigned descent point. *(implied: profile line is flat to left of circle [ADP symbol] ..).*	compliance target usage	descent location	info timing
C_50.	Begin descent at assigned descent point.* *(implied: profile line slopes to right of circle..)*	compliance target usage	descent location	info timing
C_51.	Maintain constant descent rate until shallowing for crossing restriction.* *(implied: profile line is straight in segment between dashed lines..)*	compliance target usage	crossing altitude	info timing
C_52.	Pass through bottom of descent waypoint while in descent.* *(implied: profile line slanted downward [BOD] symbol)*	compliance target usage		

***NOTE: these are plausible inferences based on the graphic, but not part of the procedure.**

C_53.	"Maintain cruise altitude and airspeed until reaching assigned descent point." *(reinforced by placement on graphic)*	compliance target usage	cruise airspeed, descent location, speed transition	info identity timing
C_54.	"Maintain descent speed within +/- 10 knots until slowing for crossing restriction." *(reinforced by arrow and placement on graphic)*	compliance target usage	descent speed, crossing speed	info identity timing
C_55.	"Initiate descent and speed changes at assigned descent point."	compliance target usage	cruise airspeed, descent location, speed transition	info identity timing
C_56.	"If VNAV T/D is within +/- 5nm of this point, ..."			condition
C_57.	"... aircraft may descend using VNAV."			method
C_58.	Preceding note refers to assigned descent point. *(implied by arrow from note to [ADP] symbol)*	compliance target usage		info identity
C_59.	"Expect radar vectors." ...	what to expect		
C_60.	... (after passing metering waypoint.) *(location of note)*	what to expect		
C_61.	Speed and altitude are not defined after metering waypoint. *(implicit: no gray boxes; no profile line past [wpt] symbol)*	what to expect		

C_62.	Procedure ends at metering waypoint. *(implicit: no gray boxes; no profile line past [wpt] symbol)*	compliance target usage		
C_63.	"FMS NOTE": (special note for those using FMS).	procedure applicability		
C_64.	"If the VNAV T/D occurs more than 5nm from the assigned descent point ..."	compliance target usage	notify ATC	info identity condition
C_65.	"...contact ATC."		notify ATC	method
C_66.	Crossing restrictions at bottom of descent. *(text boxes with arrows, attached to bottom-of-descent symbol)*	what to expect compliance target usage	crossing speed, crossing altitude	
C_67.	Two different bottom of descent possibilities. *(two boxes)*	what to expect	crossing speed, crossing altitude	
C_68.	(One bottom of descent waypoints is) "TOMSN."	procedure applicability	crossing speed, crossing altitude	info
C_69.	"Cross [TOMSN] at FL190..."	compliance target value	crossing speed, crossing altitude	info
C_70.	"...and 250 knots."	compliance target value	crossing speed, crossing altitude	info
C_71.	(A second bottom of descent waypoints is) "RAMMS."	procedure applicability	crossing speed, crossing altitude	info
C_72.	"Cross [RAMMS] at 17000'..."	compliance target value	crossing speed, crossing altitude	info
C_73.	"...and 250 knots."	compliance target value	crossing speed, crossing altitude	info

IMPORTANT NOTES

- **Mid-descent speed changes given by ATC do not cancel PRECISION DESCENT crossing restrictions.**
- Intermediate descent altitudes are not incorporated in this procedure. However, ATC requests to maintain intermediate altitudes may be made due to traffic. Expect to resume PRECISION DESCENT upon clearing traffic.
- Updated descent wind data may be provided by ATC for entry in the FMS.

Figure C6. Important Notes block.

C_74. (The following are) "**IMPORTANT NOTES**".	what to expect document contents		
C_75. "**• Mid-descent speed changes** [might be] **given by ATC...**" (during Precision Descent.)	what to expect	descent speed	info identity info source
C_76. "**...speed changes...do not cancel PRECISION DESCENT crossing restrictions.**"	compliance target usage	crossing speed, crossing altitude	
C_77. "Intermediate descent altitudes are not incorporated in this procedure."			
C_78. "ATC requests to maintain intermediate altitude may be made..."	what to expect		info identity info source
C_79. "...due to traffic."	what to expect		
C_80. "Expect to resume PRECISION DESCENT upon clearing traffic."	what to expect	crossing speed, crossing altitude	
C_81. "Updated descent wind data..."	CTAS concept		info identity
C_82. "...may be provided..."	what to expect		
C_83. "...by ATC..."	CTAS concept		
C_84. "...for FMS entry."			method

APPENDIX C

PART 5: CONTENT ANALYSIS OF NASA FLIGHT MANUAL BULLETIN

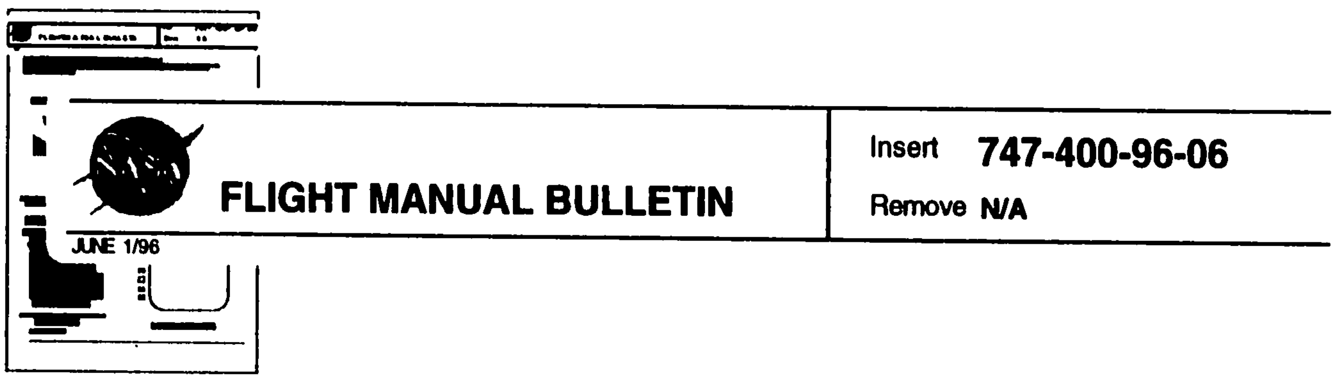
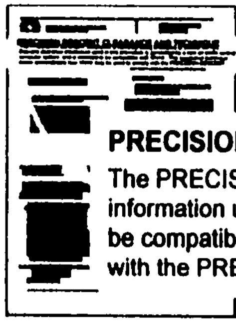


Figure C7. FMB header bar.

Proposition	ATC Procedure Information Category	ATC Procedure Compliance Measure	Cockpit Task Information Category
B1. (Document is a) "Flight Manual Bulletin."	document contents	-	
B2. (Document has a) "NASA" (logo.)	document contents	-	
B3. (Document is published by NASA.)	document contents	-	
B4. (Document dated) "June 1996."	document contents, procedure applicability	-	
B5. (Document is current.)	document contents	-	
B6. (Document format resembles United Airlines Flight Manual Bulletins.)	document contents	-	

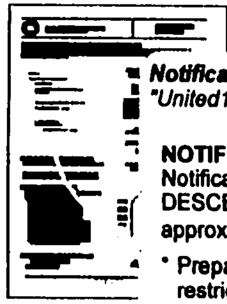


PRECISION DESCENT CLEARANCE AND TECHNIQUE

The PRECISION DESCENT Clearance is currently being evaluated at Denver ARTCC. Descent clearance information used in this procedure is generated by a new air traffic control computer system, and is intended to be compatible with VNAV. The suggested technique below demonstrates how VNAV may be used to comply with the PRECISION DESCENT.

Figure C8. Introductory paragraph.

B7. (About:) "Precision Descent Clearance..."	document contents	-	
B8. (About:) "Precision Descent... Technique."	document contents	-	
B9. "Precision Descent Clearance is currently being evaluated..."	procedure applicability, what to expect	-	
B10. "...at Denver..."	procedure applicability	-	
B11. "...ARTCC."	CTAS concept	-	
B12. " Descent clearance information [is] used in [a] procedure..."	what to expect compliance target source	-	
B13. "Descent c learance information is generated by a ...computer system..."	CTAS concept	-	
B14. an "*air traffic control* computer system..."	CTAS concept	-	
B15. "a *new* air traffic control computer system..."	CTAS concept	-	
B16. "...is intended to be compatible with VNAV."	document contents	-	
B17. "The suggested technique below..."	document contents	-	
B18. "...demonstrates how..."	document contents	-	
B19. "...VNAV can be used to comply with the Precision Descent.	document contents	-	method,. purpose



Notification:
"United123, expect PRECISION DESCENT."

NOTIFICATION
Notification to expect the PRECISION DESCENT clearance will be received approximately 10 minutes before descent.

- Prepare to comply by entering the crossing restriction from the PRECISION DESCENT PLATE in the CDU LEGS page.

FORECAST WINDS
Descent forecast winds may be provided to the aircraft by ATC. If descent forecast winds are provided:

- Enter in the DES FORECAST page.

Figure C9. Notification block.

B20. "Notification to expect the Precision Descent Clearance..."	what to expect	-	
B21. "... will be received..." *(count on being notified)*	what to expect	-	
B22. "...approximately 10 minutes before descent."	what to expect	-	
B23. (After Notification, ...)		crossing speed, crossing alt.	timing
B24. "• Prepare to comply..."		crossing speed, crossing alt.	purpose
B25. "...by entering crossing restriction ..."		crossing speed, crossing alt.	method info identity
B26. "...from PRECISION DESCENT PLATE..."	compliance target source	crossing speed, crossing alt.	info source
B27. "....in CDU LEGS page."		crossing speed, crossing alt.	method, info destination
B28. "Descent forecast winds..."	what to expect	-	info identity
B29. "... may be provided..."	what to expect	-	
B30. " ...by ATC."	CTAS concept	-	info source?
B31. "If forecast winds are provided:" ...			condition, timing?
B32. ..."• enter in DES Forecast page."			method, info destination

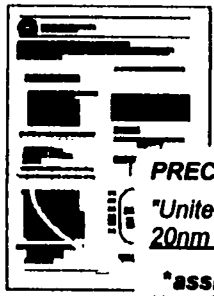


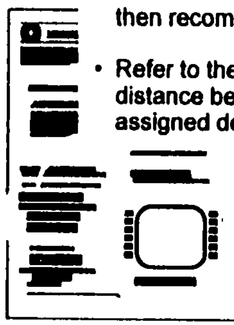
Figure C10. Precision Descent clearance.

B33. "PRECISION DESCENT Clearance" (Phraseology example)	document contents	-	
B34. "United 123, cleared for PRECISION DESCENT, 20nm West of FROGS, 300kts."	what to expect, compliance target source	-	
B35. "*assigned descent point: ... " (ADP)	compliance target source	descent location	info identity
B36. (is included in PRECISION DESCENT Clearance.)	compliance target source	descent location	info source
B37. "...actual values will vary" (from 20nm West of FROGS.)	compliance target usage	-	info source
B38. "**assigned descent speed: ..."	compliance target source	descent speed	info identity
B39. " (ADS) (is included in PRECISION DESCENT Clearance.)	compliance target source	descent speed	info source
B40. "...actual values will vary" (from 300kts.)	compliance target usage	descent speed	info source

Descent Point
The aircraft may descend using VNAV, ***if*** the VNAV T/D is within 5 nm of the assigned descent point.

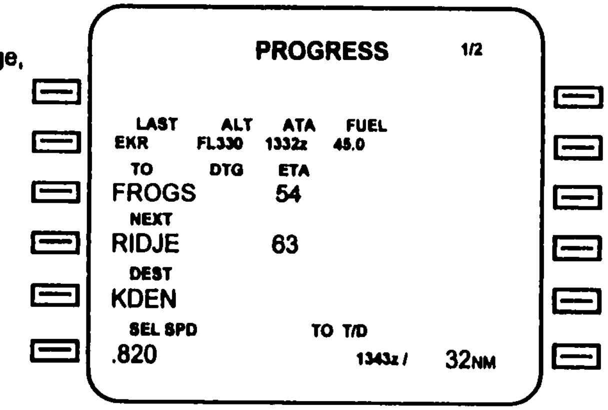
To compare the VNAV T/D to the assigned descent point:

- Enter the assigned descent speed in the DES page, then recompute the VNAV T/D.
- Refer to the PROG page to determine the distance between the new VNAV T/D and the assigned descent point (see ***EXAMPLE***).



EXAMPLE

"... 20 nm West of FROGS, 300 kts."

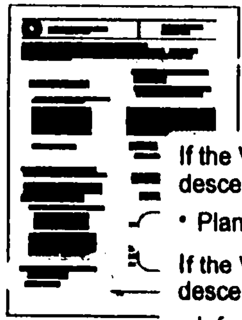


In this example, the aircraft is 54 miles west of FROGS and 32 miles west of the VNAV T/D. Therefore the T/D is 22 miles west of FROGS, or 2 miles from the assigned descent point.

Figure C11. Top of Descent comparison.

B41. (About) "Descent Point".	document contents	notify ATC descent location	
B42. "The aircraft may descend using VNAV ..."		notify ATC descent location	method
B43. "...if the VNAV T/D is within [tolerance] of the assigned descent point".		notify ATC descent location	info identity, condition
B44. (ADP tolerance is) "...5nm..."	compliance target usage	notify ATC descent location	
B45. "To compare the VNAV T/D to the assigned descent point:" (do the following.)	compliance target usage	notify ATC, descent location	purpose
MISSING INFORMATION/STATEMENT: "...and to prepare for VNAV descent" (second reason for following; notmentioned.)	***compliance target usage***	***cruise airspeed, descent speed, speed transition***	***purpose***

B46. "Enter the assigned descent speed..."		cruise airspeed, descent speed, speed transition	imethod
B47. "...in the DES page..."		cruise airspeed, descent speed, speed transition	info destination, method
B48. "...then ..."			timing, condition
B49. "...recompute the VNAV T/D."			method
B50. (after recomputing the T/D)			timing, condition
B51. "Refer to the PROG page..."			method
B52. "...to determine difference..."	compliance target usage	notify ATC, descent location	purpose
B53. "...between the new T/D and the assigned descent point."	compliance target usage	notify ATC, descent location	info identity
B54. (Use the) "...new T/D..." (in the comparison.)		notify ATC	info identity
B55. "See EXAMPLE" (for method.)		notify ATC	method
B56. (Use PROG page to monitor a/c position relative to the T/D.) *(implicit)*		descent location	method
B57. (Use PROG page to monitor a/c position relative to the ADP.) *(implicit)*		descent location	method
B58. from example: T/D-ADP-difference = ADP-distance-from-FROGS - (a/c-distance-to-FROGS minus a/c-distance-to-T/D)	compliance target usage	notify ATC	info identity method



- Plan to recapture the VNAV path after descent has been initiated.
- Consider using ALT HOLD to prevent early descent while waiting for descent clearance.

If the VNAV T/D is within 5 nm of the assigned descent point:

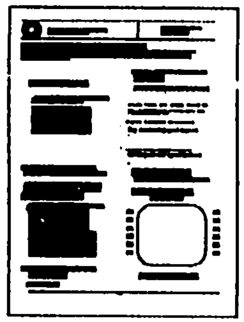
- Plan to use VNAV to initiate and fly the descent.

If the VNAV T/D is ***not*** within 5 nm of the assigned descent point:

- Inform ATC.

Figure C12. Descent planning.

B59. "If the VNAV T/D is within 5nm of the assigned descent point: ..."	compliance target usage	descent location, speed transition	condition, info identity
B60. "...Plan to use VNAV to initiate and fly the descent ."	compliance target usage	descent location, speed transition, descent speed	method
B61. "If the VNAV T/D is ***not*** within 5nm of the [ADP]: ..."	compliance target usage	descent speed, crossing speed, crossing alt.	condition, timing, info identity
B62. "...Inform ATC." (and...)	compliance target usage	notify ATC	method
B63. "...Plan to recapture the VNAV path ..."	compliance target usage	descent speed, crossing speed, crossing alt.	method
B64. "...after descent has been initiated." (and...)	compliance target usage	descent speed, crossing speed, crossing alt.	timing
B65. "... Consider using ALT HOLD ..."		descent location	method
B66. "...to prevent early descent..."		descent location	purpose
B67. "...while waiting for descent clearance."		descent location	timing



CRUISE-TO-DESCENT SPEED TRANSITION
Note that VNAV's descent initiation method is compatible with the recommendations below.

If assigned descent speed is slower than cruise airspeed:

- Begin deceleration ***after*** reaching the assigned descent point.

If assigned descent speed is faster than cruise airspeed:

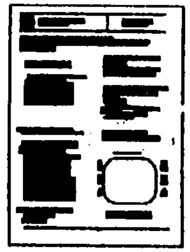
- Maintain cruise or assigned mach until assigned airspeed is reached.

Figure C13. Top of Descent speed transition.

B68. (About:) "CRUISE-TO-DESCENT SPEED TRANSITION"	document contents	speed transition	
B69. "...VNAV's descent initiation method is compatible ..."		speed transition	method
B70. "...with the recommendations below."	document contents		
B71. "If assigned descent speed is slower than cruise airspeed..."	compliance target usage	speed transition	info identity condition
B72. "...Begin deceleration ..."	compliance target usage	speed transition	
B73. "...after reaching the assigned descent point."	compliance target usage	speed transition	timing
B74. "If assigned descent speed is faster than cruise airspeed..."	compliance target usage	cruise airspeed, speed transition	info identity condition

MISSING STATEMENT: "Begin acceleration after ADP." (Should have been here, but wasn't.) ***timing***

B75. "...Maintain cruise mach..."	compliance target usage	cruise airspeed, speed transition	info identity
B76. "...or assigned mach [if provided]..."	compliance target usage	cruise airspeed, speed transition	info identity
B77. "...until assigned airspeed is reached."	compliance target usage	cruise airspeed, speed transition	info identity, timing
B78. (Use assigned or cruise mach to accelerate to assigned airspeed.)	compliance target usage	cruise airspeed, speed transition	info identity



SPEED IN DESCENT
- Use thrust or drag as needed to maintain assigned descent speed within 10 knots.

Figure C14. Speed during descent.

B79. (About:) "SPEED IN DESCENT"	document contents	descent speed	
B80. "...maintain assigned descent speed ..."	compliance target usage	descent speed	purpose, info identity
B81. "...within 10 knots."	compliance target usage	descent speed	purpose, info identity
B82. "Use thrust ..."		descent speed	method
B83. "...as needed..." *(if energy is inadequate)*		descent speed	condition
B84. "...to maintain assigned descent speed..."		descent speed	purpose, info identity
B85. "Use ...drag..."		descent speed	method
B86. "...as needed..." *(if energy is excessive)*		descent speed	condition
B87. "...to maintain assigned descent speed..."		descent speed	purpose, info identity

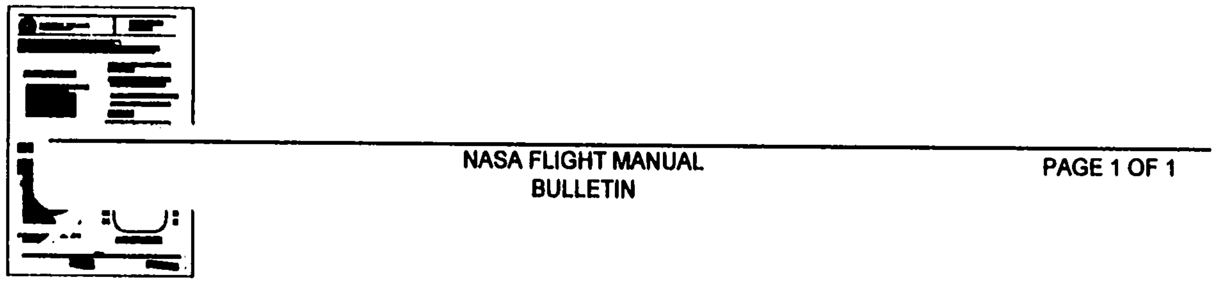


Figure C15. FMB footer bar.

B88. (Document is a) "...Flight Manual Bulletin."	document contents	-	
B89. (Document is a) "NASA Flight Manual Bulletin."	CTAS concept	-	
B90. "PAGE 1 of 1" (This page is the complete Bulletin.)	document contents	-	

APPENDIX D

Precision Descent Task Model Overlays

PART 1: TASK INFORMATION FROM PRECISION DESCENT BULLETIN*

Task Activities:	*Condition*	*Data needed; source & destination*	*Timing: after*	*Timing: until*
I Prepare for descent **B24**	notified to "expect Precision Descent"		Precision Descent Notification **B23**	
A. Configure VNAV				
1. enter descent forecast winds **B30,32**	data available **B31**	descent winds, altitudes source: ACARS dest: DES Fcst page **B32**		
2. enter crossing restriction (at meter fix) **B26**	metering waypoint known	metering wpt. crossing restrictions source: Chart **B26** dest: LEGS page **B27**		
3. enter descent speed in FMS **B46**	data available	Ass. Descent [Mach/]spd source: Dscnt. Clr. **B39** dest: DES page **B47**	Precision Descent Clearance ?	
B. Configure MCP/Enable Descent	cleared for descent			
1. enter altitude		metering waypt. xr-alt source: Chart dest: MCP alt window		
2. use ALT HOLD to prevent early descent **B65, 66**	mismatch between MCP altitude and cleared altitude (and/or) not cleared to descend at VNAV T/D. **B67**			
3. push alt. knob	MCP dialed to cleared alt. (and) in VNAV mode (and) past T/D when cleared to descend			
C. Determine where to descend	data available	Assigned Descent Pt. source: Dscnt. Clr. **B36**	Precision Descent Clearance	
1. configure ADP	time available			
a) Method 1: configure ADP as user- defined wpt		dest: LEGS page		
b) Method 2: configure ADP fix circle		dest: FIX page		
2. determine a/c position relative to ADP **B57?**				
a) Method 1: monitor ADP on PROG page **B57**				

* Information presented in the Bulletin is color coded in Green, and annotated with a numeric cross-reference to the document content list in Appendix C.

b) Method 2: monitor ADP on Nav Display	ADP fix circle programmed (or) ADP waypoint programmed			
3. determine if T/D is within 5nm of ADP B46	VNAV programmed for Precision Descent B50	Assigned Descent Point. Assigned Descent Speed source: Dscnt Clr B36,39 ADP window source: Chart		
a) Method 1: use PROG page information B51-55, 58				
b) Method 2: use Nav Display	fix circles programmed			
4. choose descent location	T/D within 5nm of ADP			
D. Monitor planned descent point relative to a/c position	Descent point determined	point within ADP window source: Dscnt. Clr.; Chart		
1. Method 1: monitor PROG page				
2. Method 2: monitor CRZ page				
3. Method 3: monitor Nav Display				
E. contact ATC B62	T/D is more than 5nm from ADP B61			
1. contact ATC				
2. inform "T/D out of range"				
F. avoid late descent	Descent Clearance *not* received		Precision Descent Notif.	
1. monitor approach to descent				
a) Method 1: monitor T/D on PROG page				
b) Method 2: monitor T/D on CRZ page				
c) Method 3: monitor T/D on Nav Display				
d) Method 4: monitor FMS messages				
2. request descent clearance	close to T/D			within ADP window
II. Transition to Descent Speed B68	cleared for descent current spd != ADS B71-73	Ass. Descent [Mach/] Spd source: Dscnt. Clr.	within ADP window or at ADP B73	
A. Method 1: Use MCP to achieve speed target	current speed >= ADS	Assigned Descent Speed source: Dscnt. Clr.		
1. open MCP speed window	speed window blank			
2. select MCP speed	mach selected			
3. adjust MCP speed window	MCP speed window != ADS			current IAS = ADS
B. Method 2: Use MCP to achieve mach target	Assigned Descent Mach (ADM) provided (or) current spd. < ADS	Assigned Descent Mach source: Dscnt. Clr. (or) Cruise Mach		
1. open MCP Mach/IAS window	Mach/IASwindow blank			
2. select MCP mach	speed selected			
3. adjust MCP Mach window	MCP mach window != ADM			*current mach = ADM*

C. Method 3: Use VNAV to achieve (mach/)speed target B69, 70	T/D is within ADP window B42	Ass. Dscnt. [Mach/] spd source: Dscnt. Clr.		
1. enter DES (mach/)speed	Assigned Descent (Mach) Speed not programmed	Ass. Descent [Mach/] Spd source: Dscnt. Clr.		
2. engage VNAV	VNAV not engaged			
D. Method 4: Adjust V/S to achieve speed target	descent mode = V/S Mach/IAS <> assigned value	Ass. Descent Mach (or) Assigned Descent Speed source: Dscnt. Clr.		
1. increase descent rate	current mach < ADM (or) current speed < ADS			
2. decrease descent rate	current speed > ADS			current speed = ADS
III. Begin Descent	cleared for descent (a/c is within ADP window) and current speed >= ADS	ADP window location source: Descent Clr., Chart		
B. Enable descent (duplicates "config MCP")	descent not enabled			
1. set MCP alt. to cleared altitude	MCP alt window <> cleared altitude	metering wpt. xr-alt source: Chart		
2. push alt. knob	current mode is ALT HOLD? *(check)*			
C. start descent				
1. Method 1: V/S mode	descend before VNAV T/D (or) VNAV not programmed (or) above or below VNAV path (or) need to control speed			
a) push V/S button	V/S not engaged			
b) enter vertical speed	V/S window <> desired V/S	'desired' vertical speed		
2. Method 2: FLCH mode	descend before T/D (or) VNAV not programmed (or) need to control speed			
a) push FLCH button	FLCH not engaged			
3. Method 3: VNAV mode	T/D within ADP window VNAV profile acceptable			
a) push VNAV button	VNAV not engaged?			
b) line select Descend Direct	planned descent pt. before VNAV T/D			
D. Inform ATC				
1. contact ATC				
2. announce "leaving altitude"				past ADP win.
IV. Maintain Descent Speed within tolerance B80-81	in descent	Ass Dscnt Spd B80 source: Dscnt. Clr., tolerance B81	current speed = ADS	

A. Method 1. adjust thrust or drag to achieve speed target B82-87	VNAV mode engaged (or) energy excess/deficit (and) current speed outside tolerance (or) current speed <>I ADS	
1 increase throttles B82	speed error is small (or) current speed < ADS (and) speed brakes retracted (and) energy deficit	
2. decrease throttles	current speed < ADS (and) throttles are not fully retracted (?) (and) energy excess	
3. increase speed brakes B86	current speed < ADS (and) speed brakes are retracted (and) speed error is small (or) adjustment is short term (and) energy excess	
4. decrease speed brakes	current speed < ADS (and) throttles are not fully retracted (?) (and) energy deficit	
B. Method 2: Speed intervene to achieve speed target	in VNAV mode (and) speed error in VNAV approaches tolerance (or) VNAV speed <> ADS	
1. push speed knob	speed window blank	
2. adjust MCP speed	MCP IAS window <> ADS	
C. Method 3: Use FLCH to achieve speed target	VNAV not programmed (or) speed error in VNAV approaches tolerance (or) ADS changed	
1. push FLCH button	not in FLCH mode	

2. adjust MCP speed	MCP IAS window <> ADS			
D. Method 4: Use VNAV to maintain speed target	VNAV speed and profile acceptable			
1. engage VNAV	VNAV mode not active			
2. close MCP speed window	MCP speed window open (not blank)			
E. Prepare VNAV to maintain speed target	VNAV setup not current			
1. enter DES speed	VNAV speed <> ADS			
2. enter metering waypoint crossing restriction	entered wpt-xr <> cleared wpt-xr	metering wpt. crossing restriction source: Chart		capture xr-alt; (or) decel distance
V. Prepare to meet crossing restr's		metering wpt. crossing restriction source: Chart	capture xr-alt; (or) decel distance	
A. Monitor vertical path error				
B. Monitor distance to metering waypoint		metering wpt. source: Chart		
C. estimate distance needed to decelerate		metering wpt., crossing airspeed source: Chart		
D. monitor/adjust speed as needed				
1. monitor airspeed				
2. determine energy excess/deficit				
3. adjust throttles				
4. adjust speed brakes				
5. adjust MCP speed				
D. monitor/adjust descent rate as needed.				
1. monitor altitude				
2. adjust vertical speed...				metering waypoint

PART 2: TASK INFORMATION FROM PRECISION DESCENT CHART[1]

Task Activities:	*Condition*	*Data needed; source & destination*	*Timing: after*	*Timing: until*
I. Prepare for descent	notified to "expect Precision Descent"		Precision Descent Notification	
A. Configure VNAV				
1. enter descent forecast winds **C81, 84**	data available **C82**	descent winds, altitudes source: ACARS dest.: DES Fcst Page		
2. enter crossing restriction (at meter fix)	metering waypoint known	metering wpt. crossing restrictions source: Chart **C31, 32** dest: LEGS page		
3. enter descent speed in FMS	data available	Ass. Descent [Mach/]spd source: Dscnt. Clr. **C28** dest: DES page	Precision Descent Clearance?	
B. Configure MCP/Enable Descent	cleared for descent			
1. enter altitude		metering waypt. xr-alt source: Chart dest: MCP alt window		
2. use ALT HOLD to prevent early descent	mismatch between MCP altitude and cleared altitude (and/or) not cleared to descend at VNAV T/D			
3. push alt. knob	MCP dialed to cleared alt. (and) in VNAV mode (and) past T/D when cleared to descend			
C. Determine where to descend	data available	Assigned Descent Point source: Dscnt. Clr. **C24**	Precision Dscnt Clearance	
1. configure ADP	time available			
a) Method 1: configure ADP as user-defined wpt		dest: LEGS page		
b) Method 2: configure ADP fix circle		dest: FIX page		
2. determine a/c position relative to ADP				
a) Method 1: monitor ADP on PROG page				
b) Method 2: monitor ADP on Nav Display	ADP fix circle programmed (or) ADP wpt programmed			
3. determine if T/D is within 5nm of ADP **C84**	VNAV programmed for Precision Descent	Assigned Descent Point, Assigned Descent Speed source: Dscnt. Clr. ADP window source: Chart		
a) Method 1: use PROG page information				
b) Method 2: use Nav Disp.	fix circles programmed			
4. choose descent location	T/D within 5nm of ADP			

[1] Information presented in the Chart is color coded in blue and annotated with a numeric cross-reference to the document content list in Appendix C.

D. Monitor planned descent point relative to a/c position	Descent point determined	point within ADP window source: Dscnt. Clr.; Chart		
1. Method 1: monitor PROG page				
2. Method 2: monitor CRZ page				
3. Method 3: monitor Nav Display				
E. contact ATC **C65**	T/D is more than 5nm from ADP **C64**			
1. contact ATC				
2. inform "T/D out of range"				
F. avoid late descent	Descent Clearance *not* received		Precision Descent Notif.	
1. monitor approach to descent				
a) Method 1: monitor T/D on PROG page				
b) Method 2: monitor T/D on CRZ page				
c) Method 3: monitor T/D on Nav Display				
d) Method 4: monitor FMS messages				
2. request descent clearance	close to T/D			within ADP window
II. Transition to Descent Speed	cleared for descent current speed != ADS	Ass. Dscnt [.Mach/] Spd source: Dscnt. Clr.	within ADP window (or) @ ADP **C44-46,56**	
A. Method 1: Use MCP to achieve speed target	current speed >= ADS	Assigned Descent Speed source: Dscnt. Clr.		
1. open MCP speed window	speed window blank			
2. select MCP speed	mach selected			
3. adjust MCP speed window	MCP speed window != ADS			current IAS = ADS
B. Method 2: Use MCP to achieve mach target	Assigned Descent Mach (ADM) provided (or) current speed < ADS	Assigned Descent Mach source: Dscnt. Clr. (or) Cruise Mach		
1. open MCP Mach/IAS window	Mach/IAS window blank			
2. select MCP mach	speed selected			
3. adjust MCP Mach window	MCP mach window != ADM			*current mach = ADM*
C. Method 3: Use VNAV to achieve (mach/)speed target	T/D is within ADP window	Ass. Descent [Mach/] Spd source: Dscnt. Clr.		
1. enter DES (mach/)speed	Assigned Descent (Mach) Speed not programmed	Ass. Descent [Mach/] Spd source: Dscnt. Clr.		
2. engage VNAV	VNAV not engaged			
D. Method 4: Adjust V/S to achieve speed target	descent mode = V/S Mach/IAS <> assigned value	Ass. Descent Mach (or) Ass. Descent Speed source: Dscnt. Clr.		
1. increase descent rate	current mach < ADM (or) current speed < ADS			
2. decrease descent rate	current speed > ADS			current spd. = ADS
III. Begin Descent	cleared for descent (a/c within ADP window) (and) current speed >= ADS	ADP window location source: Descent Clr., Chart		

B. Enable descent (duplicates "config MCP")	descent not enabled			
1. set MCP alt. to cleared altitude	MCP alt window <> cleared altitude	metering wpt. xr-alt source: Chart		
2. push alt. knob	current mode is ALT HOLD? *(check)*			
C. start descent			**C50, 55**	
1. Method 1: V/S mode	descend before VNAV T/D (or) VNAV not programmed (or) above or below VNAV path (or) need to control speed			
a) push V/S button	V/S not engaged			
b) enter vertical speed	V/S win. != desired V/S	'desired' vertical speed		
2. Method 2: FLCH mode	desc. before VNAV T/D (or) VNAV not programmed (or) need to control speed			
a) push FLCH button	FLCH not engaged			
3. Method 3: VNAV mode **C27**	T/D within ADP window **C26, 56, 57**			
a) push VNAV button	VNAV not engaged?			
b) line select Descend Direct	planned descent point before VNAV T/D			
D. Inform ATC				
1. contact ATC				
2. announce "leaving altitude"				past ADP window
IV. Maintain Descent Speed within tolerance **C29, 54**	in descent	Assigned Descent Speed source: Dscnt. Clr., tolerance **C29**	current speed = ADS **C47**	
A. Method 1: adjust thrust or drag to achieve speed target	VNAV mode engaged (or) energy excess/deficit (and) current speed outside tolerance (or) current speed <> ADS			
1. increase throttles	speed error is small (or) current speed < ADS (and) speed brakes are retracted (and) energy deficit			
2. decrease throttles	current speed < ADS (and) throttles are not fully retracted (?) (and) energy excess			
3. increase speed brakes	current speed < ADS (and) speed brakes retracted (and) speed error is small (and) energy excess			

4. decrease speed brakes	current speed < ADS (and) throttles are not fully retracted (?) (and) energy deficit			
B. Method 2: Speed intervene to achieve speed target	in VNAV mode (and) speed error in VNAV approaches tolerance (or) VNAV speed <> ADS			
1. push speed knob	speed window blank			
2. adjust MCP speed	MCP IAS window <> ADS			
C. Method 3: Use FLCH to achieve speed target	VNAV not programmed (or) speed error in VNAV approaches tolerance (or) ADS changed			
1. push FLCH button	not in FLCH mode			
2. adjust MCP speed	MCP IAS window <> ADS			
D. Method 4: Use VNAV to maintain speed target	VNAV speed and profile acceptable			
1. engage VNAV	VNAV mode not active			
2. close MCP speed window	MCP speed window open (not blank)			
E. Prepare VNAV to maintain speed target	VNAV setup not current			
1. enter DES speed	VNAV speed <> ADS			
2. enter metering waypoint crossing restriction	entered wpt-xr <> cleared wpt-xr	metering wpt. crossing restriction source: Chart		capture xr-alt (or) decel distance **C47, 54**
V. Prepare to meet crossing restr's		metering wpt. crossing restriction source: Chart	capture xr-alt (or) decel distance	
A. Monitor vertical path error				
B. Monitor distance to metering waypoint		metering wpt. source: Chart		
C. estimate distance needed to decelerate		metering wpt., crossing airspeed source: Chart **C66-73**		
D. monitor/adjust speed as needed				
1. monitor airspeed				
2. determine energy excess/deficit				
3. adjust throttles				
4. adjust speed brakes				
5. adjust MCP speed				
D. monitor/adjust descent rate as needed.				
1. monitor altitude				
2. adjust vertical speed...				metering waypoint